DESIGN OF A COMPUTER ASSISTED PROPOSAL PREPARATION PROCEDURE.

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ABSTRACT.

The purpose of this dissertation is to investigate the feasibility of automating the present manual methods of Control System design and proposal preparation. This was accomplished by analysing the present Control Industry procedures to determine the requirements of a Computer Assisted Procedure. A Computer Assisted Proposal Preparation System was then designed and developed to demonstrate the benefits attainable through automation.

A general discussion of the Control Industry environment is given in Chapters one and two. Here, the control system design activities and proposal preparation techniques are discussed.

There are numerous control systems with design procedures which are ripe for automation. In Chapter three, one of these control systems is chosen as the test case for the development of a Computer Assisted Proposal Preparation procedure.

Before system design can begin, the system requirements, or problem definition, must be established. This is accomplished in Chapter four by first describing in detail the manual design method and then providing detail requirements for an automated system.

The design methodology followed, and the actual design activity is discussed in Chapter five. With the system design established, the construction activity could begin. Chapter six discusses the system construction.

A final working system is then presented in Chapter seven. Sample design sessions and a complete users' manual are shown. The conclusions derived from the design of the system and from the testing of the system are found in Chapter eight.

It is the intention of this dissertation to provide a clear understanding of the applicability of Computer Assisted procedures to the Design and Proposal preparation activities of Process Control Systems.

CHAPTER 1.

INTRODUCTION.

Presently, numerous Instrument and Control System Suppliers are expending many man/hours manually designing control systems and preparing proposals for customer applications. As the control industry grows in size and complexity, the need for some formal method of handling the myriad of control system design variations becomes a necessity, not a luxury.

The purpose of this dissertation is to investigate the practicality of employing Computer techniques to the design of process control systems and to proposal preparation. The dissertation describes the design, development and use of a Computer Aided Design and Proposal Preparation System (CAPP). Experience gained from the development of CAPP and user reaction to CAPP has been used to provide the conclusions concerning use of Computer techniques to proposal preparation.

Presently Control System Design and Proposal Preparation, which is performed entirely by Design Technicians, is done manually and thus in a very time-consuming manner. Two major types of activity are involved:

1) the technical type, i.e. specification evaluation and control philosophy definition and,

2) the clerical type, i.e. equipment selection, pricing and documentation.

It is the clerical functions which involve the largest expenditure of time.

However, the very mechanical nature of these functions make them applicable to Computer Aided Design techniques.

CABP was designed as a logical and efficient aid to the performance of these "clerical" functions. This system is a tool which provides more effective use of technical personnel by eliminating the mechanical tasks and increasing the available time for specification evaluation and control system definition.

The idea of CAPP occured to the author while involved in preparing system design and proposals for a popular Instrument Company. Observing the need for a more efficient utilization of man power, the idea was presented to management. Encouragement to proceed lead to the development of CAPP.

CHAPTER 2

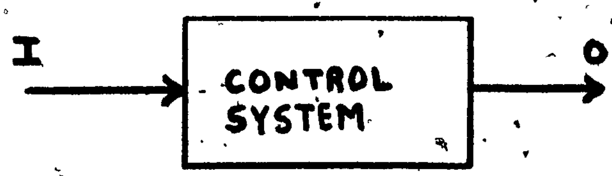
ENVIRONMENT

2.1. CONTROL SYSTEM DESIGN ACTIVITIES

For the purpose of this discussion, a system is defined as an arrangement of components connected or related in such a manner as to form or act as an entire unit. A control system then consists of an arrangement of physical components connected in such a manner as to command, direct or regulate itself or another system or process. The basic control system is illustrated by Fig. 2.1. An input signal "I" is measured from the process to be controlled and is applied to the control system. The control system reacts according to a control philosophy in order to provide a predictable output signal "O" which is applied to the process.

There are three steps in the evolution of a control system design. The first consists of the development of the Control Philosophies. These philosophies, which may vary from simple feedforward proportional type control to complicated simulations, are a result of Advanced Control Theory research. The second step is the design of the physical equipment required to realize the control philosophies. The final step involves the selection and arrangement of the physical equipment to achieve a control philosophy over the range of service conditions defined by a process.

The control philosophy development and the design of equipment to achieve these philosophies result from the Research and Development Activities within an Instrument Company. The equipment selection and arrangement is an Engineering activity. Once a suitable control system has been developed. it is then offered to industry.



CONTROL SYSTEM.

Fig. 2.1.

The Instrument Company prepares proposals for control systems based on customer specifications. The Engineering department analyses the customer specifications to determine the service conditions and which control philosophy will achieve the desired results. Based on this, the control system equipment is then selected and priced. As the number of control systems and philosophies grow in size and complexity, the manual techniques of equipment selection and pricing which are currently popular are becoming inadequate.

2.2. TYPES OF PROCESS CONTROL SYSTEMS.

Control systems currently available from Instrument Companies fall into two basic categories: 1) Analog Control Systems and 2) Digital Control Systems. There are various new types of control systems being developed, i.e. Fluidic Control Systems, however these can usually be classified as one of the two basic types.

Each of the two basic categories can be further subdivided. For Analog Control Systems there are:

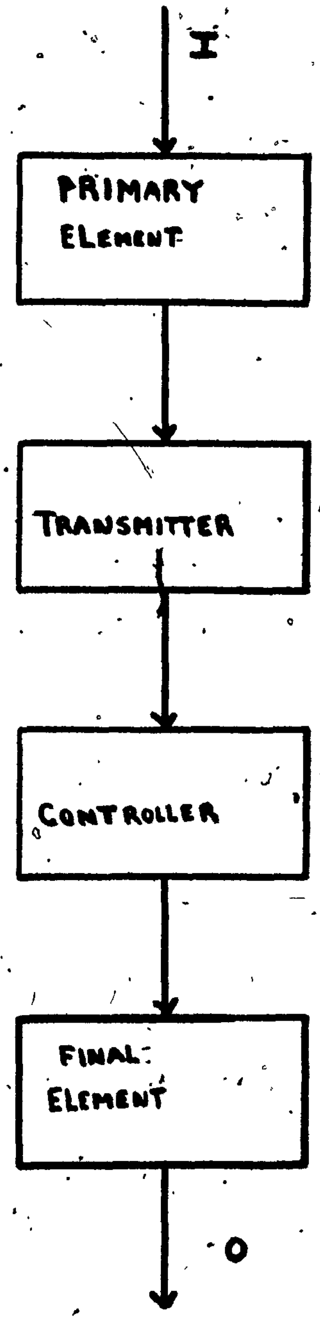
Mechanical Analog Control Systems
Electric Analog Control Systems
Pneumatic Analog Control Systems

The subdivisions of Digital Systems are:

Hardwired Digital Control Systems
Programmable Digital Control Systems

There may be other types of control systems available, but the above represent the popular systems being offered on the market by control companies today.

All control systems consist of the basic components shown in Fig.2.2. The equipment required to make up these components is different for each system type. For example the controller for a complicated programmable digital control system may be the central processing unit of a large scale computer, whereas the controller for a simple pneumatic control system may be a simple pneumatic adder. Although the details of each selection process will differ with the equipment, the design approach for each control system type is the same. In all cases, equipment selection procedures follow logical steps once control philosophies and variables are defined.



CONTROL SYSTEM COMPONENTS.

Fig. 2.2.

2.3.4 CURRENT PROPOSAL PREPARATION METHODS.

In the process control industry, it is typical that a customer prepares a set of control system specifications and submits them to various Instrument Companies for competitive bids. Once a customer's control system specifications are received, a control system is designed to satisfy the specifications and priced accordingly. Since no two processes are identical and because of equipment characteristics, a specific system design and equipment selection must be performed for each set of specifications, before an accurate price can be determined.

The current design procedure consists of two major activities: 1) customer specification interpretation and 2) equipment selection and proposal preparation.

The specification interpretation consists of a commercial interpretation, i.e. terms of payment, discounts, etc., and a technical interpretation. Functional aspects are interpreted in conjunction with the defined control philosophies and standards documented in the Instrument Companies' control application manuals.

Once the control philosophies and process variables have been defined, a set of manual steps are followed to arrive at the final equipment selection. These steps consist of various calculations and table "look-up" procedures which take the process variables into account. After the equipment required for the system has been selected and all interconnections established, the control system price is calculated. The Design Technician looks up an enormous price catalog to determine the price of each piece of equipment and its accessories.

The final steps consist of the Proposal Preparation and Control System Documentation. Price make-up sheets must be prepared, equipment lists tabulated, specification sheets completed and descriptive paragraphs prepared. These are then assembled into a final proposal document. A detailed description of an equipment selection procedure is shown in Chapter four and Fig. 4.1. on page 14.

The purely technical and interpretative activities of specification interpretation consume approximately 25% of the time required to produce a final design and proposal. The remaining 75% is consumed by mechanical activities which are begging to be automated.

CHAPTER 3.

APPLICATION DESCRIPTION.

3.1. AUTOMATED PROPOSAL PREPARATION METHOD.

As the control industry grows in size and complexity, a more convenient method of performing system design functions is necessary. The method must decrease the number of man-hours spent per proposal, maintain or improve the present quality as well as provide quicker designs and accurate prices to meet a more competitive situation.

A computer assisted method is the proposed solution. The proposed procedure still consists of two major activities: 1) customer specification interpretation and 2) equipment selection and proposal preparation. The specification interpretation is identical to the current procedure. A control philosophy is established and all process variables are defined. However, now the equipment selection and proposal preparation activities are automated. Information concerning the control philosophy and process variables are entered as inputs into the computer assisted design system. The system functionally duplicates the current equipment selection procedures, selecting equipment, based on predetermined criteria, to suit the process conditions. The system then provides a system proposal documentation in a form identical to that now prepared manually.

The primary goal of the proposed system is to relieve skilled technical staff from the mechanical and clerical tasks which consume 75% of the time spent in system design and proposal preparation. This has the effect of reducing overhead thus making the company more profitable. The secondary goal of the proposed system is to provide more accurate equipment selection and pricing procedures. This results in a more competitive proposal.

3.2. APPLICATION SELECTION.

Typically, management is not convinced by words alone, especially when money must be spent before it can be saved. Therefore, a Computer Aided Proposal Preparation System (CAPP) was designed and developed to demonstrate the benefits that are obtainable by automation of control system design procedures.

Every large instrument company offers each of the five control system types previously described. Since the design procedures followed for all control system types are somewhat similar, the conclusions drawn from the automation of one are applicable to all. CAPP was intended as a test case, hence it was developed to automate the equipment selection and proposal preparation for one type of control system of a popular instrument company.

In order to create the most effective impact, the system chosen had to satisfy the following requirements:

1. The control system will not change substantially for at least three years.
2. There is a large number of proposals for this control system prepared in a year.
3. A high percentage of the design procedure is applicable to automation.
4. There is a high number of man-hours spent on each proposal.
5. The control system is a profitable product of the instrument company.
6. The Decision Makers are very familiar with the object of automation.

The instrument company chosen offers five types of control systems. These consist of:

1. Pneumatic Analog Boiler Control Systems
2. Mechanical Analog Boiler Control Systems

3. Electric Analog Boiler Control Systems
4. Fixed Wired Digital Burner Control Systems
5. Programmable Digital Data Acquisition System.

It is the Analog Boiler Control Systems which best satisfies the above requirements.

A unique feature of these analog control systems is that each of the sub-systems described in Fig 2.2., page 7 , is independent of the other. That is, the equipment for one can be selected and priced independent of the other.

The major elements in the FINAL ELEMENT sub-system are the control valves. The control valves, and hence their design procedures, are identical for all three analog systems. Also, the control valve design procedures consume approximately 50% of the time to design the entire control system. For these reasons, the valve selection and pricing procedure, for one of the many valve classes, was selected, as the test case for CAPP.

CHAPTER 4.

SYSTEM REQUIREMENTS.

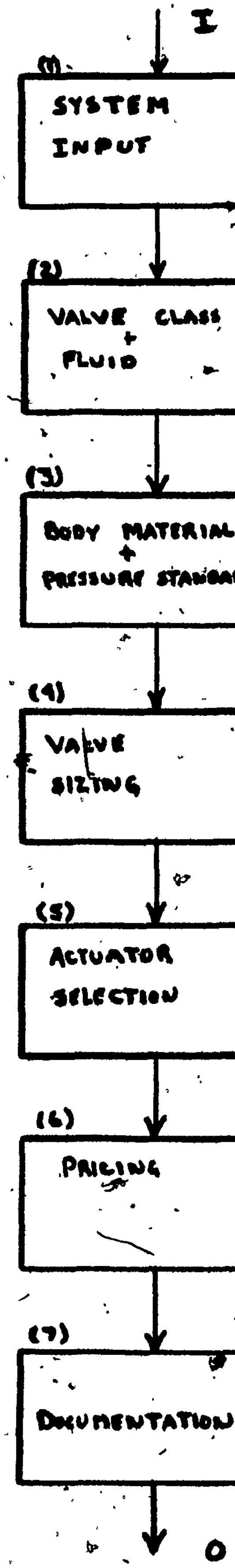
4.1. VALVE PROPOSAL PREPARATION PROCEDURE.

The importance of correctly selecting control valves cannot be over emphasized. From a purely economic viewpoint, an undersized valve cannot do the job and must be replaced; too large a control valve costs more initially and has a higher maintenance cost. This could result in thousands of wasted dollars. Considering the operation, an oversized valve provides poor control and can cause system instability.

Similar to all control system design procedures, the valve design procedure consists of 1) specification interpretation and valve system design and 2) valve selection and proposal preparation. During specification interpretation, the control philosophies are determined, i.e. shut-off control, modulating control, etc. and the values of all service variables are established. This information is then used to perform the valve selection and proposal preparation. It is this second procedure which CAPP automates.

The sequence of events which are followed in the selecting and pricing of a control valve are shown in Fig.4.1. Item one, System Input, is a result of the specification interpretation stage. Specifically, the types of information which must be available to select a valve are:

1. Kind of Service, i.e. feedwater, gas flow, pump recirculation, etc.
2. Operating Conditions
   a. Fluid Type
   b. Static Inlet Pressure
   c. Temperature



CONTROL VALVE SELECTION PROCEDURE.

Fig. 4.1.

d) Capacity

e) Pressure Drop

f) Velocity

All these inputs, and others, are determined from the customer specifications. More system input details may be found in Appendix A.1.

Each instrument company manufactures different classes or types of valves; each designed for specific kinds of service. Item two consists of choosing the instrument company's valve class which is best suited for the service defined in Item one. This class choice is a result of table look-up procedures which are detailed in Appendix A.2.

Once the valve class or type has been determined, it is necessary to select a body material and body pressure standard that can withstand the pressure and temperature conditions of the fluid involved. Item three involves consulting the USAS charts and graphs to arrive at a suitable body material and pressure standard. Since the valve class selected does not come in every body material and pressure standard which the USAS charts cover, it is necessary only to consult those applicable. Details of the USAS charts and graphs are shown in Appendix A.3.

Valve size is determined by a set of variables:

1. Valve Body, which is a housing for internal parts having inlet and outlet flow connections,
2. Cage dimensions, which define the size of the controlling port through which process fluid flows.
3. Body Inlet and Outlet areas.
4. Stem Diameter, which provides a connecting point for a valve actuator.

A complete description of valves is given in reference Item four contains the procedures necessary to determine the values of these sizing coefficients. The cage diameter and stroke are determined by the valve port area. The port area, which is the maximum area of the controlling cavity, is a result of a calculation which is a function of various system inputs. The result of velocity calculations determines the inlet and outlet area. Together the cage dimensions and inlet and outlet dimensions define the body size and stem diameter. The calculations which are performed are shown in Appendix A.4.

The Actuator selection procedure in item five, consists of selecting an Actuator size as a function of absolute inlet pressure. The table look-up procedure is detailed in Appendix A.5.

Finally, the valve design is now available. In item six, a price table is used to determine the price of the particular valve selected. In item seven, the valve documentation is performed. Appendix A.6, shows the Valve Price Make Up Sheets, and the Specification Sheets which must be completed.

The foregoing is a detailed account of the selection procedure which is now performed manually. The ultimate requirement of an automated system is that it functionally duplicates the present selection procedures.

4.2. CAPP INTERFACE REQUIREMENTS.

A Computer Assisted Proposal Preparation procedure, CAPP, has been designed to automate the Valve Proposal Preparation procedure previously described. Before a design procedure commences, the system requirements must be determined. The input requirements of CAPP are:

4.2.1. System Inputs.

CAPP must provide the ability to enter the input variables required for valve selection. A complete list of all inputs is shown in Appendix B.1.

4.2.2. Natural Dialogue.

The input system dialogue must be design for a non-computer oriented professional person. The system will be used by Control System Design Technicians with a low panic threshold. The dialogue should not require extensive training or involve elaborate procedures. The man-system interface should be as natural as possible in order to avoid annoyance and criticism which may result in rejection of the system.

4.2.3. User Assistance.

The input system should provide user assistance. The system should instruct the user as to what inputs are required, in what units they should be entered, what value ranges are permissible, etc.

4.2.4. Error Proof.

The input system should minimize the likelihood of operator error. When the operator makes an error, i.e. entering an unreasonable input of detecting it, and it should be corrected in a way that does not antagonize the operator.

4.2.5. <u>Interactive</u>.

The input system must provide for design flexibility. If the user decides part way through the procedure that he would like to change a previously entered input value, he should have the ability to do so.

4.2.6. <u>Instructions</u>.

The input system should provide operating instructions. The user should be able to request various messages:

1. Describe system functions
2. Describe system operation
3. Provide a list of input variables
4. Provide an example of its use.

4.2.7. <u>Bullet Proof</u>.

The input system must be immuned against irrational operator behaviour.

4.2.8. <u>Maintainable</u>.

The input system must be easily expanded and maintained.

4.3 CAPP SELECTION PROCEDURE REQUIREMENTS.

The CAPP Selection Procedures must functionally duplicate the present selection procedure previously described. Specifically, it must calculate the values of the variables listed in Appendix B.2, using the equations described in Appendix A. In addition to performing calculations, it must maintain a data base of the data described in Appendix A , so that the table look-up procedures can be performed.

The result of the procedure must be a valve design identical to that achieved if the selection was done manually. Additional requirements of the automated selection procedure are:

4.3.1. <u>Modular</u>.
The automated selection procedure should be naturally modularized identical to the manual system illustrated in Fig. 4.1. page 14.

4.3.2. <u>Accurate</u>.
The accuracy of the calculations should be better than the two decimal place accuracy currently attainable via manual methods.

4.3.3. <u>Maintainable</u>.
The automated procedure must allow easy expansion and easy maintenance.

4.4. CAPP OUTPUT REQUIREMENTS.

An important requirement of CAPP is that it should provide system output similar, if not identical, to that now being produced. The specific requirements of the output system are:

4.4.1. <u>Output Variables</u>.
The CAPP output system shall provide the output variables listed in Appendix B.3.

4.4.2. <u>Input Variables</u>.
The CAPP output system shall record all input variables listed in Appendix B.1.

4.4.3. <u>Output Forms</u>.
The CAPP output system shall provide a printout similar to the Proposal Price Make-up form and the Valve Specification sheet. These forms are shown in Appendix A.6.

4.4.4. <u>Reproduction</u>.
The CAPP output shall allow for convenient reproduction.

4.4.5. <u>Quality</u>.
The CAPP output must be of a quality sufficient for direct inclusion into a customer proposal.

4.5. CAPP MISCELLANEOUS REQUIREMENTS.

The various miscellaneous requirements of a Computer Assisted Proposal Preparation System for valves are:

4.5.1. Security.

The system must be secure. Since confidential data, i.e. price, will be stored in computer files, the system must ensure that such files are not inspected by unauthorized persons nor illegally modified.

4.5.2. Reliable.

The system must be reliable. It must be operating satisfactorily 99% of the time between the hours of 8.30 a.m. to 5.00 p.m., Monday to Friday.

4.5.3. Maintainable.

The entire system must be conveniently maintained.

4.5.4. Expandable.

The entire system must be easily expanded.

4.5.5. Tested.

The system must be entirely tested and debugged prior to installation.

4.5.6. Documented.

The system design and operating instructions should be well documented.

4.5.7. Independent.

The system should be as hardware independent as possible. The system should be easily transportable from one computer system to another, and be as terminal independent as possible.

4.5.8. Response Time.

In order to achieve the requirement for design flexibility and interactivity, the response time from system input to system output must be in the order of a few minutes.

CHAPTER 5.

SYSTEM DESIGN.

The realization of a software system involves three stages after system requirements have been established. These stages are: design, construction and testing. The design stage involves making decisions and planning an overall structure so that the system will meet the stated requirements. The result of the design stage is a set of specifications from which the system can be constructed.

There are two levels of activity within the design stage. The first level consists of establishing the Processing Organization and hardware. Once this is done, the second stage, the Designing of the Programs and Data base, is approached.

5.1. PROCESSING ORGANIZATION.

The first decisions which must be made in a design process concern the man-machine processing organization and the type of hardware to be used. These decisions usually involve selection within existing constraints, based on previously established requirements. The Processing Organization decisions made during the early design stages of CAPP are:

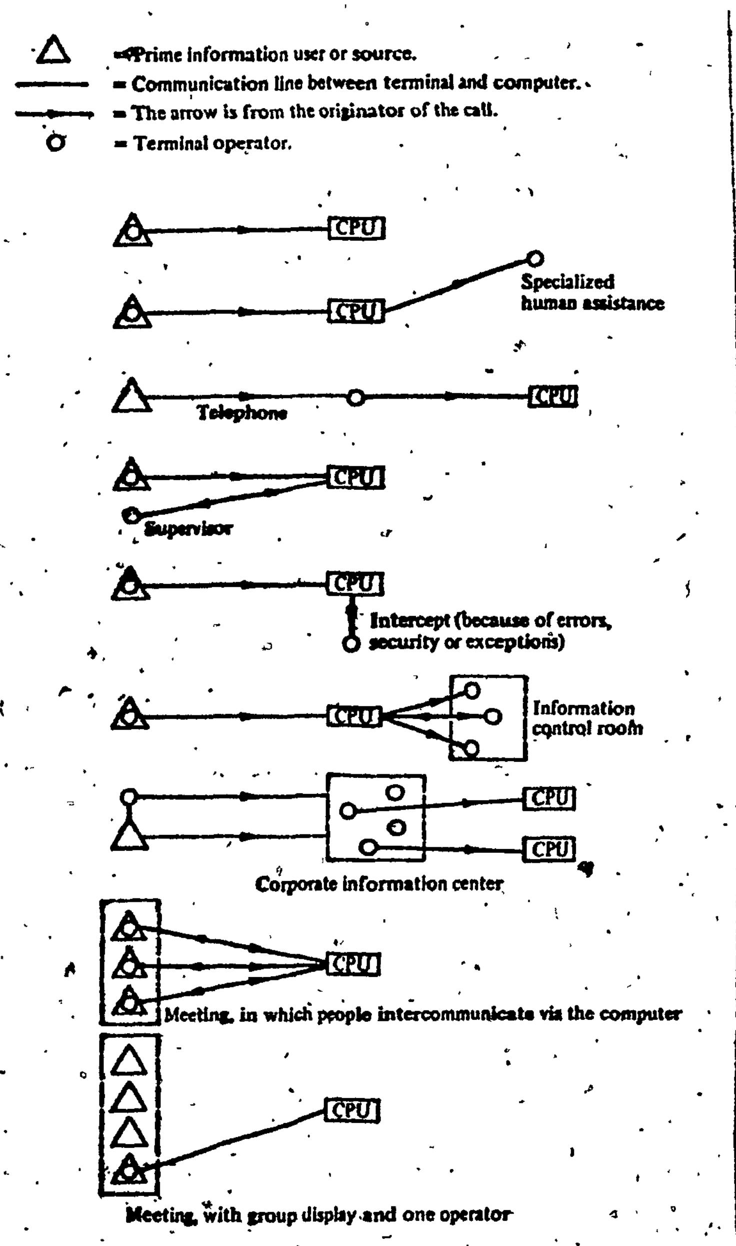
5.1.1. Information Flow.

There are a variety of methods to organize the flow of information between the computer and the user as illustrated in Fig. 5.1.

The simplest form is the user communicating directly with the computer. The second diagram shows the computer also communicating with a specialist operator who deals with situations the computer is not programmed to handle. In the third case, the user talks to an agent with a terminal over the telephone lines. In the fourth case, a supervisor monitors the conversations. In the fifth case, messages are intercepted for security reasons. The last illustrations show information flow among groups of operators. CAPP is intended to automate the present Proposal Preparation procedure as much as possible. The results of automation should be reduced man hours per proposal and reduced processing time. Also, the automated system is used by highly skilled design technicians, negating the need for a supervisor. If the above requirements are considered along with the requirement for control system design flexibility as well as close adherence to present operation procedures, then method one is the only suitable approach.

5.1.2. Batch vs. Real Time.

It has been established that the user will communicate directly with the computer. This may be accomplished via a real time terminal or via a batch terminal.



INFORMATION FLOW.

Fig. 5.1.

One of the design requirements of CAPP is a quick response time, so as to provide the necessary design flexibility. Since batch systems typically involve turn-around times of a half-a-day or longer, a real time system is the only alternative. Batch operation is a feasible consideration for a large job which requires large volumes of input and output with little need for manipulation of input values. However, for the purpose of CAPP, an interactive real time system is more suitable.

5.1.3. Installation.

There are two computer facilities available on which CAPP can be developed:

1. the Instrument Company's in-house facilities and,
2. those of a Remote Time Sharing Computer Company.

The in-house facilities cannot be used without an investment in equipment to up-grade the facility such that it can support a high level language and real time remote terminals. Thus, as well as avoiding disturbance on existing computer operations, a Time Sharing facility also represents a smaller investment. Therefore, for the test system, a Time Sharing facility is the logical choice.

5.1.4. Terminal Requirement.

The information flow decision results in the need of a terminal and computer. A real time terminal must now be Chosen.

A terminal for man-machine dialogue is a means for operator input and for computer output. The main categories of input and output are listed in Fig. 5.2. A requirement of the system is that it be as hardware independent as possible. Thus a terminal with a conventional keyboard input and an alphanumeric hardcopy output is chosen. The decisions as to the terminal response time, whether it is a display device, etc, will be decided by the system dialogue.

Input

- Keyboard
- Lever set
- or Rotary switches
- Push buttons
- Light pen for point at screen
- Finger pointing at screen
- Stylus for drawing
- Plate reader
- Badge reader

Output

- Typewriter or printer
- Alphanumeric screen
- Graphics screen
- Screen displaying film frames
- Light panel
- Graph plotter
- Dials
- Voice answerback
- Facsimile machine

Input/Output Devices on Terminals.

Fig. 5.2.

5.1.5. System Availability.

A basic requirement is that the system be available 99% of the time. This means choosing a Time-Sharing Service with a record of reliable service. It is also necessary to assure that the Time-Share Company will support the Language and Terminals used for many years. For the above reasons, and its competitive rate structure, the McGill MUSIC Time-Share System is used.

5.2. PROGRAM DESIGN METHODOLOGY.

The primary requirement of any system is that it be functionally accurate as well as reliable. Also, since the requirements of large scale systems are prone to change, the software should also be readable and easily modified and maintained.

With a complex system, reliability, functional accuracy, and maintainability become accute problems. This is a result of a complex system's many system states and the difficulty involved in organizing the program logic to handle all states correctly.

CAPP falls into the realm of complex systems. Within the system, a single action or series of actions is specified as a result of a pattern of internal conditions and controls. Every combination of conditions and controls must be accounted for, if unplanned responses are to be avoided. There are approximately 1500 possible actions which can be specified as a result of approximately 750 multi-branch conditions.

In order to design a reliable, accurate and maintainable system, it is necessary to follow a design methodology which provides techniques enabling designers to cope with complex systems.

5.2.1. Modularization.

When confronted with a complex problem, the proven technique has been to modularize the problem. Modularization consists of dividing a problem into sub-problems which can be solved separately, but which have connections with other modules. Modularization has been chosen as a technique for system production since it makes a large system more manageable. Some of the benefits available through modularization are:

1. It permits efficient use of personnel, since programmers can implement and test different modules in parallel.

2. It eliminates duplication, since a single function can be performed by a single module and implemented and tested just once.
3. It provides flexibility, since it is possible to drastically change one module without affecting others.
4. It provides comprehensibility, since one module may be tested at a time.

Once the system modules and their interconnections are established, the design and development and finally the integration of the modules begins. Thus the entire design process hinges upon effective modularization.

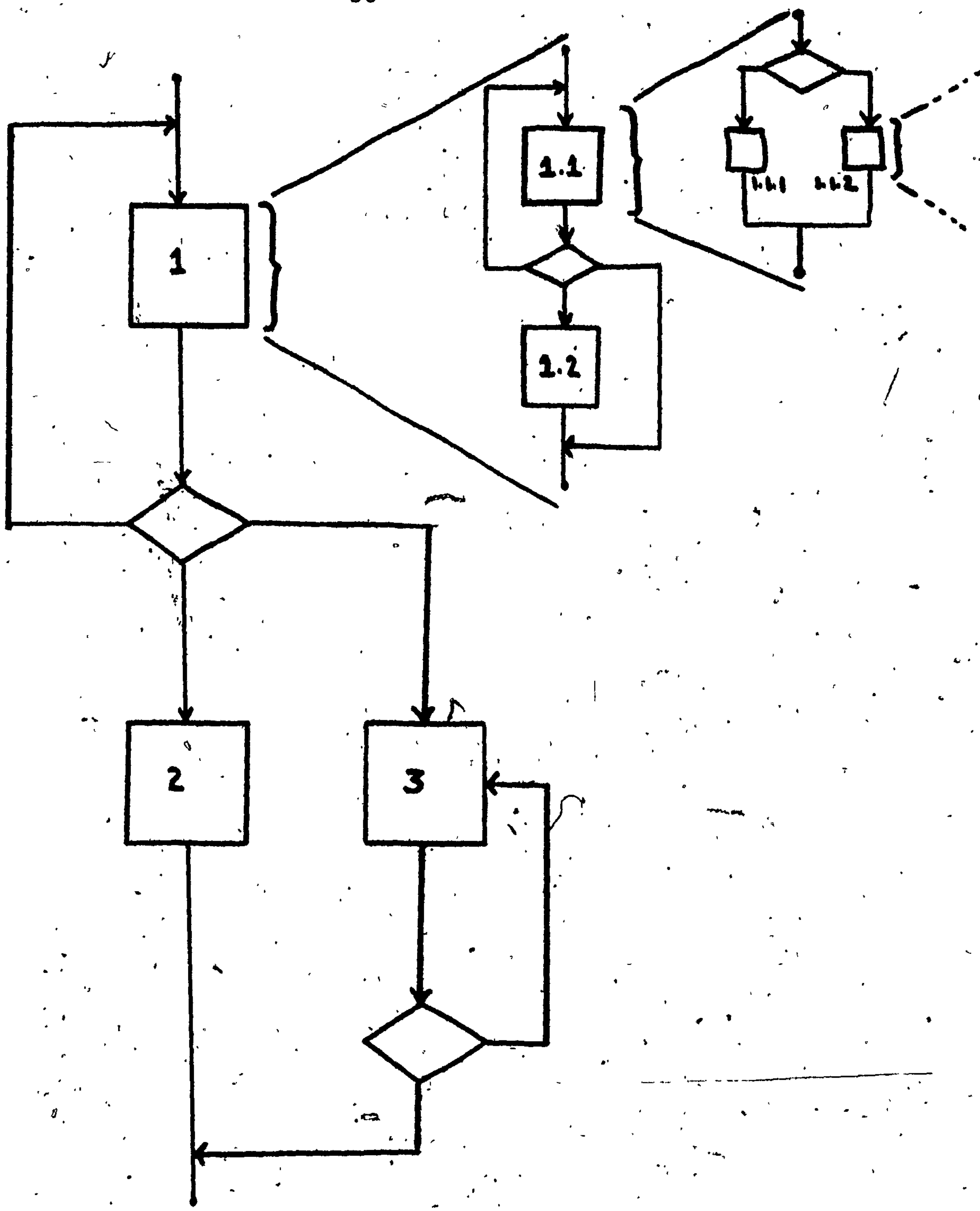
The basic idea of modularity is very good. However, the success of modularity depends directly on how well the modules are chosen. Modularization techniques have not always been reliable, therefore for the design of CAPP, a new but promising technique was adapted.

5.2.2. Traditional Design Technique.

The traditional technique for modularization is to analyse the execution time flow of the system and organize the system around each major sequential task. This design process is carried out top down on paper, using flow charts or other conceptual objects to describe the system structure in terms of macro modules. Each macro module is in turn described in terms of flow charts to define its structure in terms of lower level micro modules. Fig.5.3. shows an example of this process.

Once the design is complete, i.e. a complicated flow chart, the resulting modules are coded, unit tested, integrated into subsystems, then a system, and finally debugged as a system.

There are inherent disadvantages to this approach which conflict with some of the requirements of CAPP. These disadvantages are:



TRADITIONAL MODULARIZATION.

Fig. 5.3.

1. It is a historical fact that this approach to building systems always involves extensive debugging.
2. This approach has not proven itself successful in producing reliable software.
3. This method does not allow for the definition of a convenient system structure. The structure is entirely a result of the system characteristics and the designer's method of modularization.
4. Since there is no formal structure, there is also no controlled branching between modules. The system haphazardly branches from module to module as defined by the designer's analysis of the system.
5. This approach provides no means of testing system design until all modules have been coded and integrated.
6. This approach involves an extensive integration task.

Although it suffers from various disadvantages, this traditional method has proven useful for some time. It was an accepted technique since there was no other technique which defined how to organize system design. This, however, is no longer the case. CAPP was developed using a technique which overcomes most of the disadvantages of the traditional method.

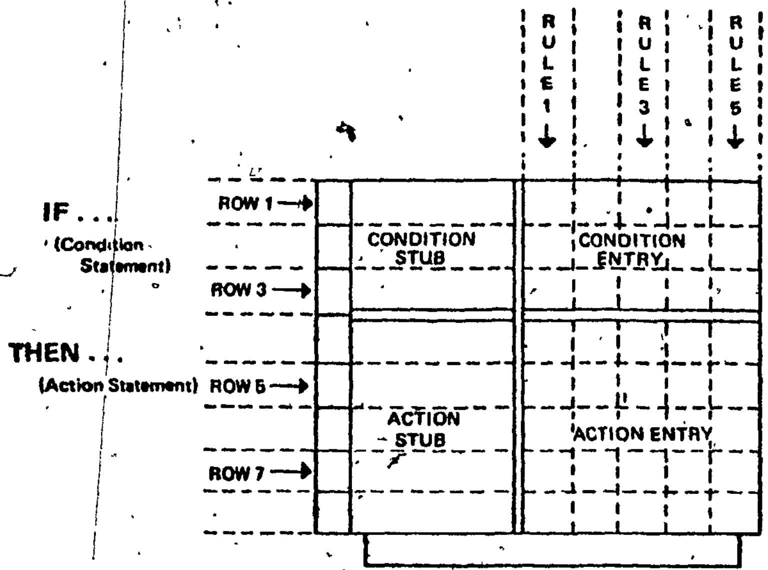
5.2.3. Structured Decision Table Programming.

CAPP was designed using a method which organizes the program design process so as to prevent most logic errors, in the first place, and to allow easy detection of those errors remaining. This results in functionally accurate, reliable and debugged software. This design methodology is called "Structured Decision Table Programming", defined by Dr. W.M. Jaworski. It consists of two techniques: the first involves using Decision Table Programming techniques, and the second consists of restricting the use of the Decision Tables so that they are structured tables.

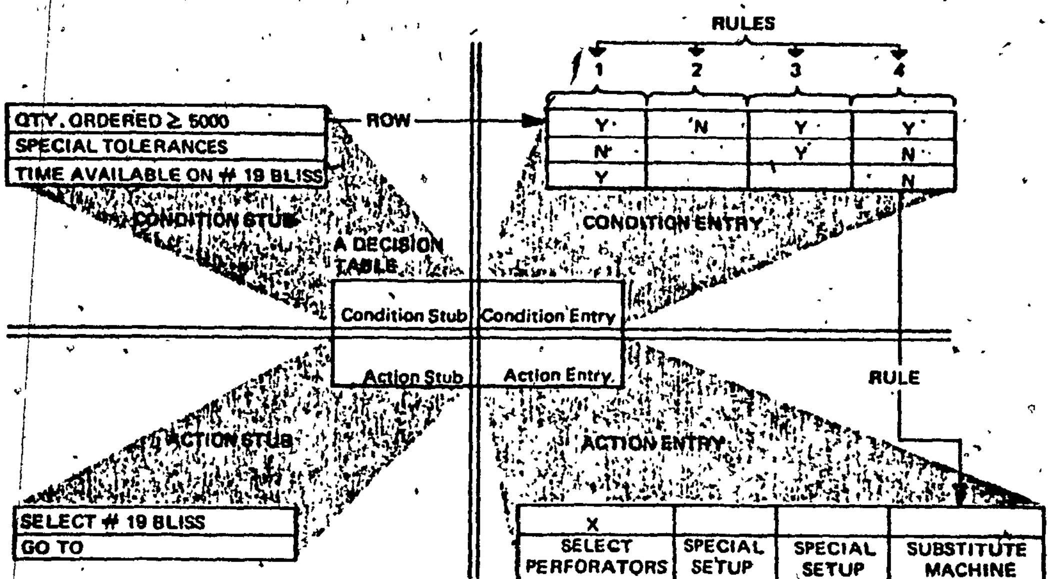
5.2.3.1. Decision Tables: For the design of CAPP, decision tables were used as the vehicle for defining the control structures. Decision tables are especially appropriate because of the many multi-branch situations in the valve selection procedure. Also, Decision Tables present the additional benefits of readable software and program documentation which is directly translatable into coding. The concise format of a decision table presents information in such a way that it can be easily read and understood, and presents logic simply so that its concepts can be readily grasped.

A Decision Table consists of a set of decision rules. Each rule contains a set of actions preceeded by a set of conditions that must be satisfied for the actions to be executed. Refer to Fig. 5.4. for an illustration of a decision table. Decision Tables are used to document applications that require the solution of complicated logical problems, such as those encountered in automated design engineering, automated manufacturing planning, bill-of-material file generation, price setting, estimating, complex payroll preparation, etc. For guidelines on the creation of decision tables refer to reference For a complete description of Decision Tables refer to references 7 to 10 and for application examples refer to reference 17.

5.2.3.2. Structured Programming: The second technique of Structured Decision Table programming requires that the Decision Tables be restructured to a structure. This structure is defined by a design methodolpgy called "STRUCTURED PROGRAMMING". This methodology involves two techniques: the first defines the system modularization and the second defines the control structures which may be used.



Basic elements of a decision table.



Exploded view of a sample decision table.

DECISION TABLE.

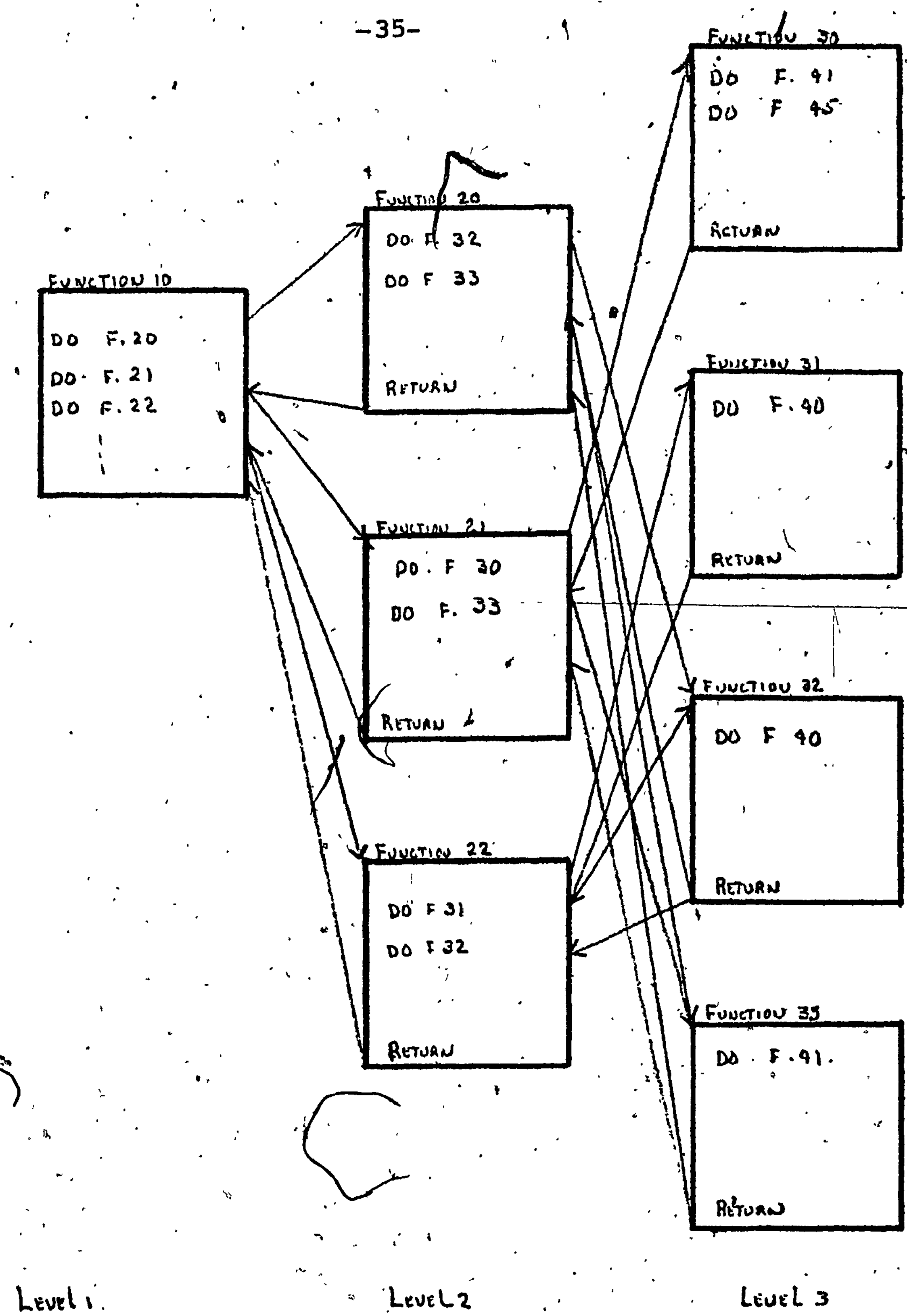
Fig. 5.4.

The first technique involves dividing the system into a hierarchy of levels, each level defining functional specifications. Thus, the modules now become functions in levels of a hierarchy, rather than modules defined by execution time flow analysis. The structured programs are then developed for each of these hierarchy levels, from top down. The highest level describes the flow of control among major functional components of the system; component names are introduced to represent the components. The names are subsequently associated with a code which describes the flow of control among still lower level components, which are again represented by their component names. The process stops when no undefined names remain. This hierarchy is illustrated in Fig. 5.5.

The second technique in structured programming defines which control structures may be used. Only the following control structures are permitted: concatenation, selection of next statement based on a tested condition, and iteration. Connection of two statements by a Go To is not permitted. The statement, however, may make use of the component names of lower level components. The control structures are illustrated in Fig. 5.6.

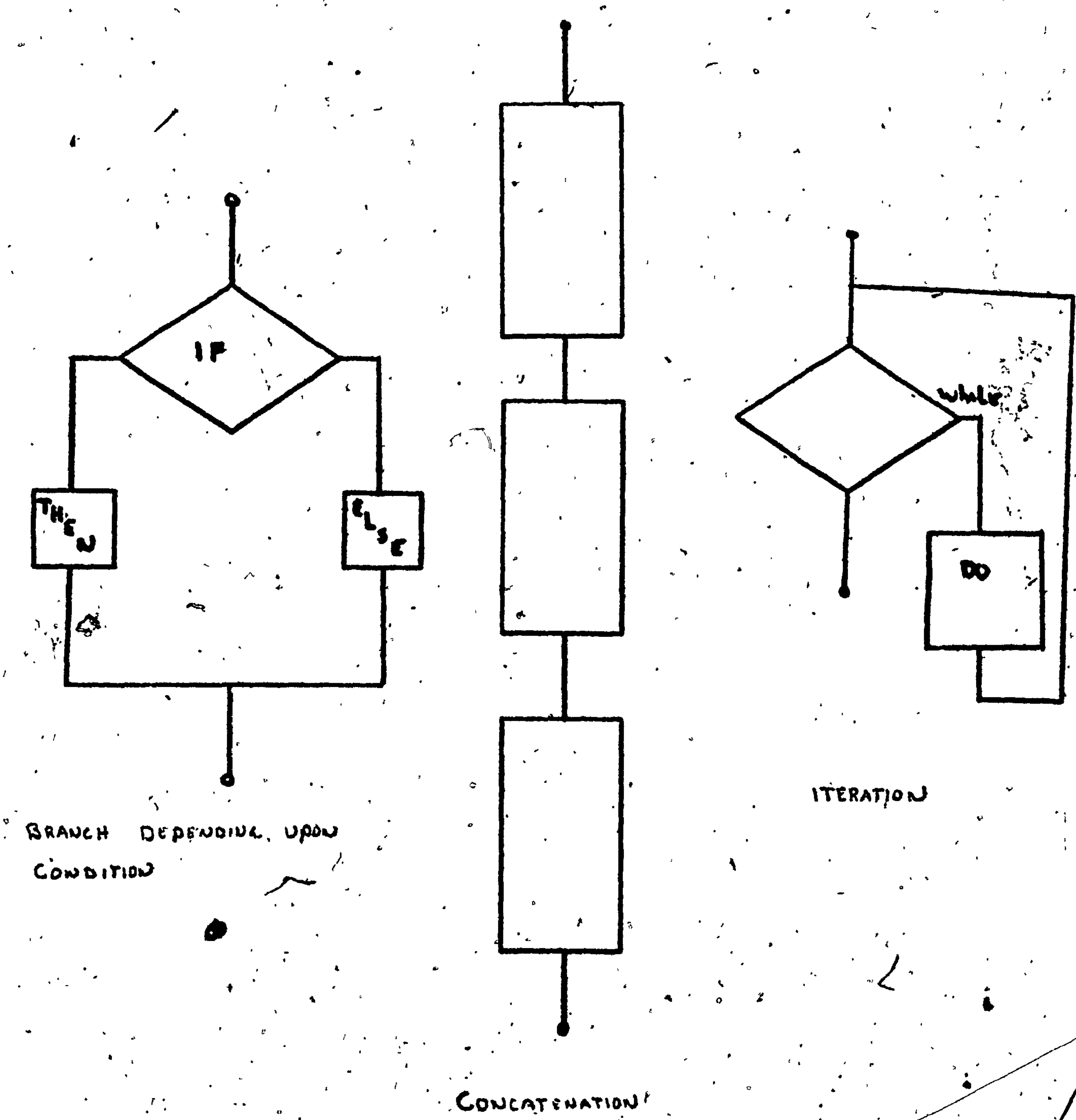
Each functional specification existing in a level defines one module of the system. A module has only one entry, at the top, and one exit, at the bottom. If other lower level modules are named within it, these modules are in turn, entered at the top and exited out the bottom, returning to the naming module.

The problem of proving the accuracy and reliability of the system and the debugging of the system occurs concurrently with the system development, in a top down fashion. The verification of a given module (function specification) requires a proof that the module specification is met by the code and named modules.



STRUCTURED PROGRAMMING

Fig. 5.5.



STRUCTURED PROGRAMMING CONTROL.

Fig. 5.6.

These named modules will be subsequently verified, possibly in terms of more detailed modules, until modules with nothing but code are reached and verified. Further details on STRUCTURED PROGRAMMING may be obtained from reference 18.

5.2.4. APL Programming Language.

Once the Decision Tables are written and the design is complete, it is necessary to program the logic contained in the decision tables.

There are four ways to convert decision tables into computer programs:

1. Manual coding from the tables,
2. Use of an interpretive computer program that interprets the tables.
3. Use of a pre-processor that converts tables into source language for input into an existing compiler.
4. Use of a compiler that translates tables directly into machine language.

Of the four methods manual, coding and the use of a pre-processor are the most widely used at present. A complete discussion of the four methods is given in reference 17 Chapter forteen.

The use of a pre-processor required that the Decision Tables be coded on the pre-processor forms before they could be translated. As well as involving additional work, the pre-processor technique does not provide a convenient interactive debugging method.

The choice of programming language to be used must facilitate this manual coding. The immediate constraints are that it must be a popular high level language, it must be supported by local Time-Sharing Companies, it must be well established and it will be supported for some time to come. Refer to reference 21 for a comparison of programming languages.

The above constraints coupled with the requirements for an interactive system and an easy method to code decision tables in a structured programming environment, lead to the decision to use APL programming language. For complete details on the use of APL refer to reference 6.

5.2.5. Criteria for Design Completion.

When using the structured programming design approach, the design process can be considered finished when the following criteria are met:

1. All hierarchy levels have been identified and the functional modules defined for them.
2. The system exists as a structured program, showing how the flow of control passes among the modules. The structured program consists of several modules, but no module, except the lowest level is completely defined; rather each module uses the names of lower level modules.

With the processing environment and design methodology established, the design of CAPP can commence.

5.3. CAPP SYSTEM DESIGN.

The design methodology established for CAPP consists of using a STRUCTURED DECISION TABLE PROGRAMMING technique.

This approach involves two iteractive techniques. The first consists of defining a hierarchy level and the function modules consist of Decision Table definitions in terms of coding and module names in lower levels. The second technique consists of establishing the control structures between these modules and the called modules in lower levels. This process proceeds from level to level. Often designs of lower levels cause changes to higher level designs, resulting in iterative design loops. Standards are established concerning the size of these functional modules and hierarchy levels.

5.3.1. Structural Size Constraints.

The design methodology established that each functional module would be defined by a Decision Table. Two of the rules of Structured Programming are: 1) Lower Level modules are not aware of the evistence of higher levels and therefore may not refer to them, and 2) Modules consist of coding and module names in lower levels. If the functional limits of the Decision Tables are controlled, then these two rules result in a controlled size of the hierarchy levels.

Readability is the main criteria to be considered when establishing a convenient Decision Table Size for the design of CAPP. The number of rules allowed is limited to sixteen with the preferrable number being eight. The second size constraint is that the combination of Conditions and Actions should fit on one page. The preferred size of Decision Tables used for the design of CAPP is shown in Fig. 5.7.

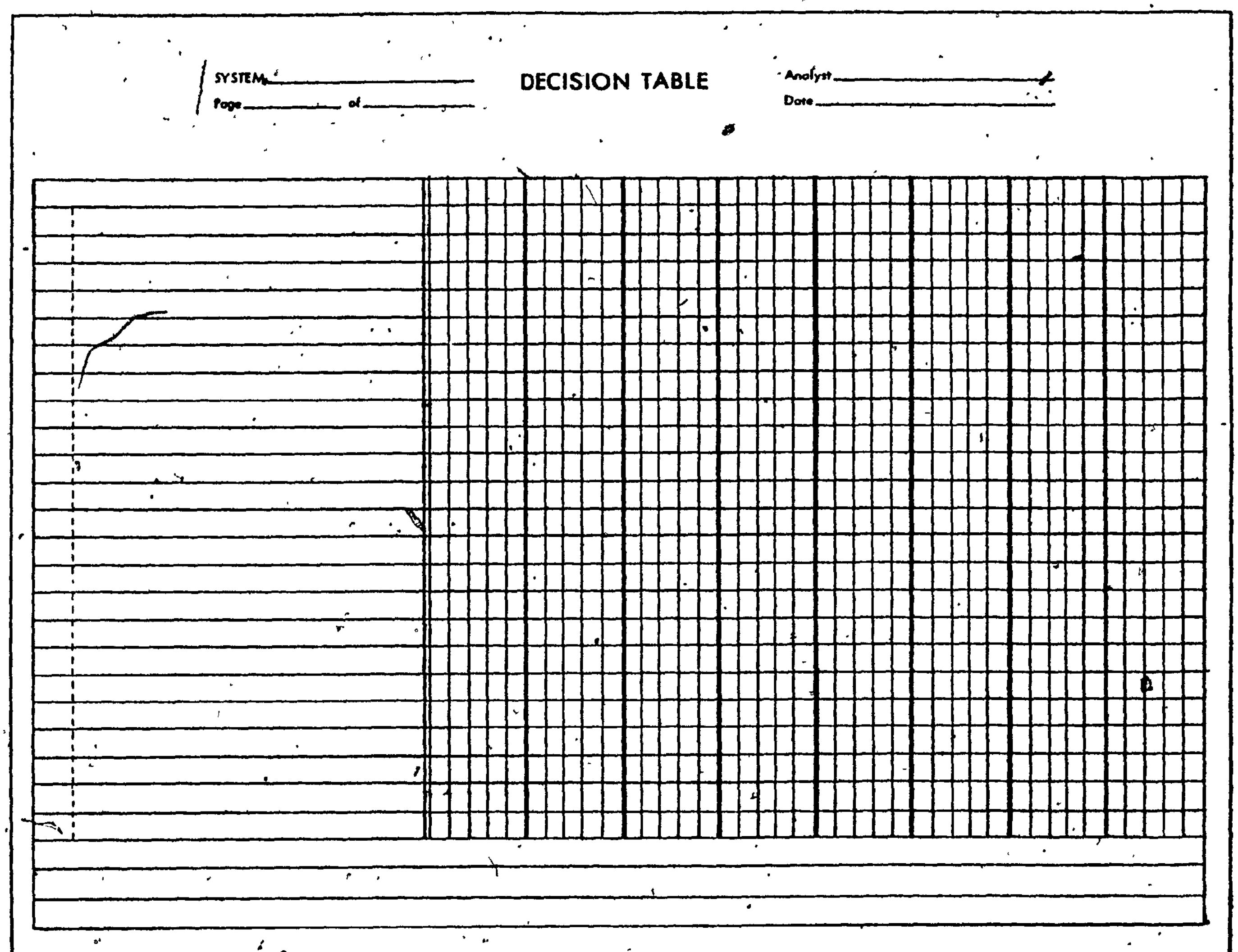

SYSTEM ______ DECISION TABLE Analyst ______
Page ______ of ______ Date ______

Fig. 5.7.

5.3.2. CAPP Program Design.

The first activity in any design process consists of establishing a thorough understanding of the problem. A complete analysis of the valve selection procedure is shown in Chapter Three.

The first activity in the Structured Programming technique consists of establishing the first levels of hierarchy and defining the functional modules within the level. Initial investigation of the valve selection process shows a very natural functional modularization. As shown in Fig. 4.1., page 14. , this modularization consists of:

Item 1 - System Inputs
Item 2 - Class Determination
Item 3 - Body Selection
Item 4 - Sizing Procedure
Item 5 - Trim Selection
Item 6 - Actuator Selection
Item 7 - Price Selection
Item 8 - System Output,

All these items make up the functional modules of the second hierarchy level. They reside in the second level because of the constraint that a module can only call modules in lower levels.

The first hierarchy level is defined by a no-condition Decision Table, T5, shown in Fig. 5.8. The control structure established by this table is concatenation.

Each function module of the second level is processed in turn. Each module is given a table number. Lower level modules associated with each module are given sequential numbers for easy identification.

The System Input Module was initially defined as a separate module which would manage the inputting of all variables required. Different valve designs required different combinations of inputs. Also, it was a requirement that the system be flexible enough to allow input variable changes part-way through a selection run.

T5 SYSTEM EXECUTION

SYSTEM ______ Page ____ of ____

DECISION TABLE

Analyst ______ Date ______

DO TABLE 101	X
DO TABLE 300	X
DO TABLE 600	X
DO TABLE 606	X
DO TABLE 1000	X
DO TABLE 1200	X
RETURN	X

T5.

Fig.5.8.

For these reasons, it was decided to request system input variables within functional modules as they are required, rather than in one place.

The Class Determination Module is responsible for choosing a valve class and process fluid depending upon which Service is entered. This Table, T101, is shown in Fig. 5.9. This function calls for the execution of Function "T129", a lower level module.

The third hierarchy level is defined by table T129, shown in Fig. 5.10. This table establishes the process Fluid depending upon the inlet pressure and temperature valves. This table calls for the execution of one of nine tables defined as T120 to T128.

These series of nine tables define a fourth hierarchy level, and the lowest for the Class Selection function.

After the execution of one of these lowest level tables, the control returns to T129, then to T101, and finally to line two of T5. Line two calls for the execution of T300.

A characteristic of Decision Tables, and one of the reasons for their use, is their readability. Appendix C contains all the Decision Tables which make up the Design of CAPP. They clearly demonstrate the design evolution of CAPP using Structured Programming techniques. For reasons of confidentiality the Price Selection Module was not included.

T101 SERVICE MANAGEMENT

Bailey SYSTEM______ Page____ of____ DECISION TABLE Analyst______ Date______

IF SERV =	01	02	03	03	04	05	06	07
IF SELROU =	01	01	01	02	01	01	01	01
SET CLASS =	1	2	2	2	4	4	1	2
SET FLUID =	STM	STM	LIQ	LIQ	LIQ	LIQ	OIL	OIL
DO T 129	X	X	X	X	X	X		
SET F =	.65	.65	.65	.65	.50	.50	.65	.65
RETURN	X	X	X	X	X	X	X	X

T 101

Fig.5.9.

T129 QUALITY OF STEAM MANAGEMENT

SYSTEM ____ DECISION TABLE Analyst ____

Page ____ of ____ Date ____

IF PA ≤	67.01	134.6	247.3	422.6	680.8	1046.
DO TABLE	120	122	123	123	124	125
RETURN	X	X	X	X	X	X

T 129

Fig.5.10.

5.3.3. CAPP Data Base Design.

During the early stages of the development of CAPP the need for a data base was considered. Data eligible for residence in a Data Base consisted of the USAS Data used in Item 3, Body Selection, of the Valve Selection procedure. This data is detailed in Appendix A.3.

Initially an attempt was made to obtain equations describing these USAS curves using a number of popular curve fitting techniques. Due to the unusual shape of the curves, an accurate fit along the entire range was not possible without a large number of high order equations. Therefore, it was necessary to utilize the data in its tabular form.

This was the only large volume of data requiring a data base. It was decided not to create a separate data base, but to code the data into a decision table. Refer to Appendix C, 600 series tables, for the results.

5.3.4. CAPP Dialogue Design.

Ultimately, the acceptance of a computer based procedure depends upon the establishment of an effective and convenient man-machine communication. No matter how sophisticated and powerful a computer-based system is, it is worth nothing if it is not accepted by the intended user. The only thing which the user sees is the system dialogue, hence its importance.

In designing the structure of the system dialogue, it is essential to take into account the shortcomings of both the user and the computer. Man is limited by his training, his programming ability, his capacity to remember and to respond logically, his patience and his personality. The logic capabilities of a man and computer are quite different. Man's thinking process is superior to the computer. He is skilled at recognizing sensual stimuli, at observing patterns and detecting relevance. He is adept at handling unforeseen occurances and dealing with low probability events. He can invent and formulate.

He is slow, unpredictable, emotional, forgetful and prone to error. The computer on the other hand, is accurate and ultra fast. It can deal with exceedingly complex sequential logical operation between man and computer.

This co-operation is dependent upon effective communications. Because of their differences, each prefers a dirrerent type of dialogue, which is not acceptable to the other. Thus, the design of the CAPP system dialogue cannot be taken lightly.

The design of man-machine dialogues is treated in depth in reference 16. Chapter two explains the design methodology which is illustrated in Fig. 5.11. This procedure is followed in designing an interactive natural dialogue for CAPP which provides user assistance and is error proof.

5.3.4.1. CAPP Input: The requirements specified that the system provides natural interactivity, user assistance, user instruction and that it be error proof. Examining existing techniques relative to the needs of CAPP, the following dialogue design results.

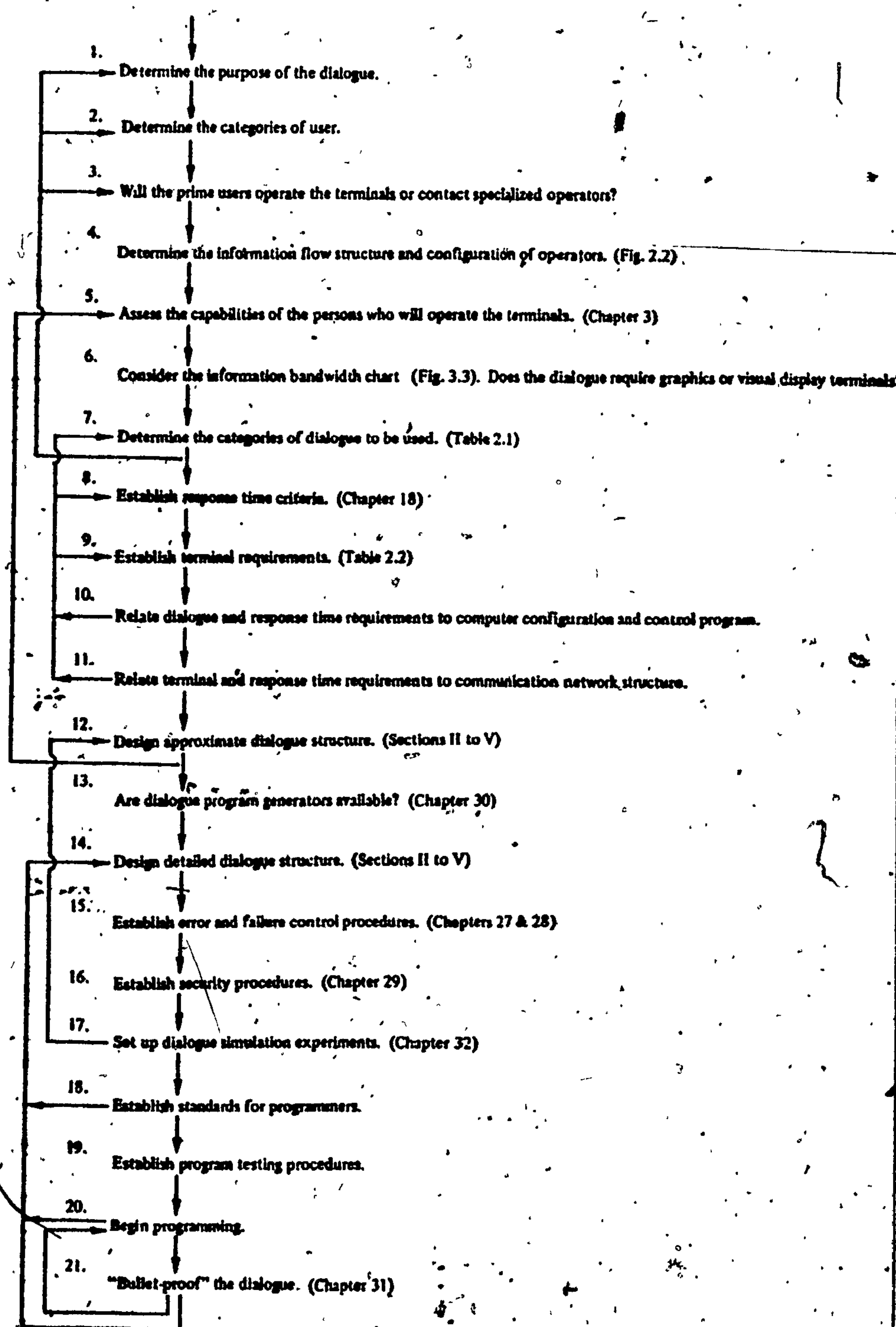
System Sign On.

```
COMPUTER ASSISTED PROPOSAL PREPARATION

                 FOR
        CLASS 1, 2, 3 VALUES
     * VERSION 1 * MAY 1973 *


           MODE SELECTION
           **************
FOR SYSTEM DESCRIPTION TYPE              :T1
FOR OPERATION DESCRIPTION TYPE           :T2
FOR LIST OF INPUT VARIABLES TYRE         :T3
FOR SAMPLE RUN TYPE                      :T4
FOR EXECUTION TYPE                       :T5
FOR TERMINATION TYPE                     :TERMINATE

   ENTER MODE
□:
```



DIALOGUE DESIGN METHODOLOGY.

Fig. 5.11.

This provides the user with the ability to obtain whatever instructions he requires. The text of each instruction panel is limited to one page of relevent data. The final text is specified in the system users manual in Chapter seven.

The program design to obtain this sign-on follows the STRUCTURED PROGRAMMING techniques. The dialogue programs are integrated into the system as high level functional modules similar to table T5. Fig 5.12 illustrates their relation with the rest of the system.

Once the execution mode, T5, is selected, the system responds with english type questions; asking for input variables, as follows:

Enter Service

```
ENTER SERVICE
□:
```

User assistance is provided by specifying the units of the input variable to be entered:

Enter Static Inlet Pressure : PS1A

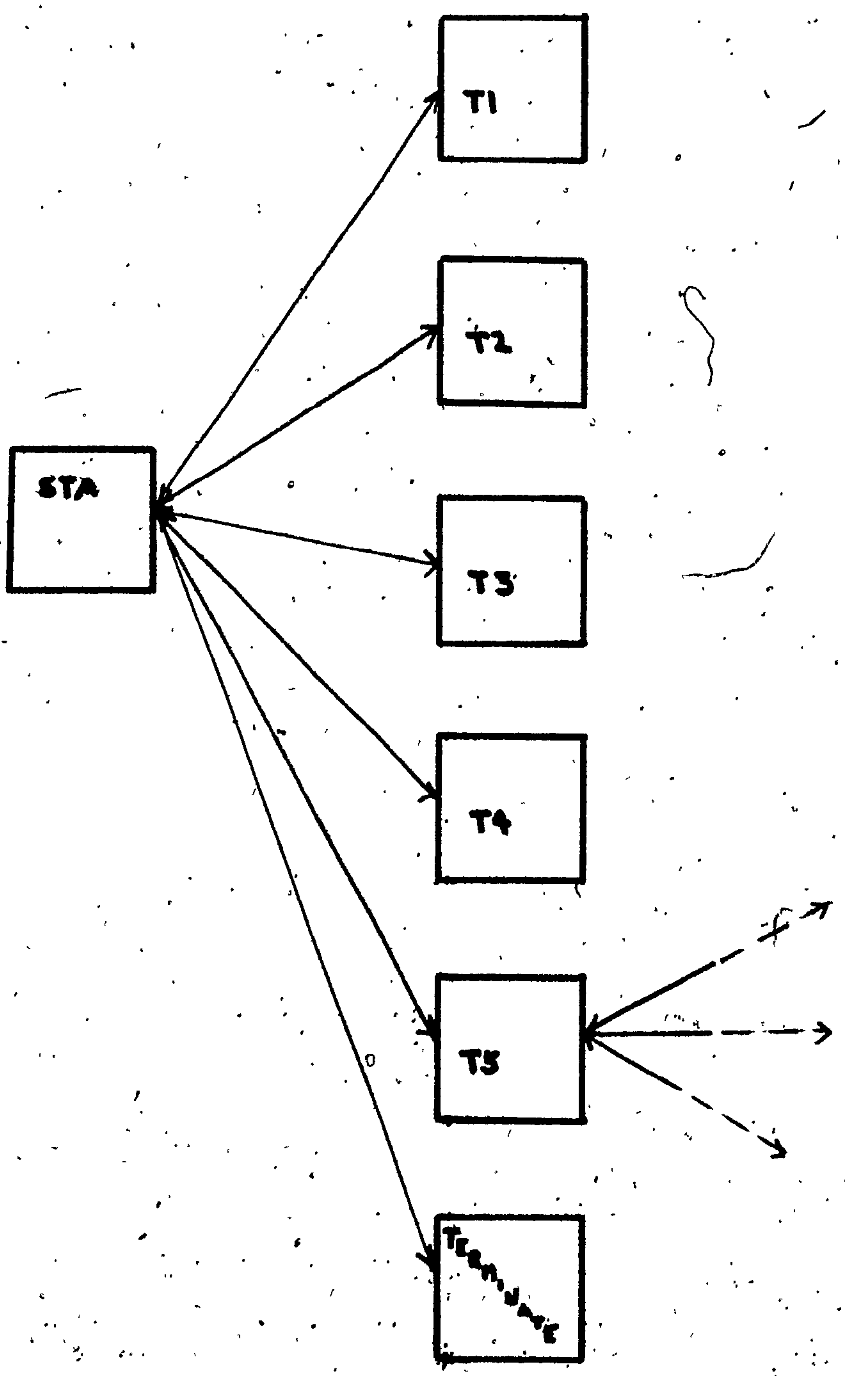
```
ENTER STATIC INLET PRESSURE : PSIA
□:
```

Qperator errors are controlled by high and low limit checking of all input variables entered. If an unreasonable value is entered, the operator is given two additional chances to enter a valid value:

Enter Temperature : F.

```
TS
ENTER SERVICE
□:
        16
SERVICE ENTERED NOT VALID; TRY AGAIN
ENTER SERVICE
□:
        1
ENTER STATIC INLET PRESSURE ; PSIA
□:
        5000
STATIC INLET PRESSURE > CRITICAL PRESSURE
ENTER STATIC INLET PRESSURE ; PSIA
□:
        6000
STATIC INLET PRESSURE > CRITICAL PRESSURE
ENTER STATIC INLET PRESSURE ; PSIA
□:
        800
ENTER TEMPERATURE ; OF
□:
        518
ENTER PRESSURE DROP ; PSI
□:
        10000
PRESSURE DROP EXCEEDS MAX OF 2000 PSI ; TRY AGAIN
ENTER PRESSURE DROP ; PSI
□:
        8000
PRESSURE DROP EXCEEDS MAX OF 2000 PSI ; TRY AGAIN
ENTER PRESSURE DROP ; PSI
□:
        2001
PRESSURE DROP EXCEEDS MAX OF 2000 PSI ; TRY AGAIN
ERROR NO    ; TABLE 601
```

```
THIS SESSION IS TERMINATING; TO RES
RT TYPE START OR ENTER MODE
LI
```



DIALOGUE PROGRAM STRUCTURE.

Fig. 5.12.

5.3.4.2. CAPP Output: Quality and duplication of present output forms are the major output requirement of CAPP. The design process is limited to specifying a computer terminal which produces reproducible hard-copy output in an 8 1/2" X 11" format. The output forms consist of the Proposal Price Make Up Sheet, the Proposal Specification Sheet and the Engineering Specification Sheet shown in Appendix A, System Output.

5.3.5. <u>CAPP Miscellaneous Requirement Design.</u>
Various miscellaneous requirements of CAPP are:

5.3.5.1. Security: The system is coded in APL using an APL Terminal. The user is given a standard ASCII terminal making it impossible for him to change system programs. Because of the need for both a user number and password, unauthorized persons are not able to enter the system. Also, all files and workspaces have security codes known only to the system owner.

5.3.5.2. Response Time: The system is designed to be terminal independent. The only requirement is for an alpha-numeric keyboard input and a hardcopy alphanumeric output. The system design is performed using a Tektronix 4013 Display Terminal. This terminal can operate from 10 characters/sec. up to 960 characters/sec. with a hard-copy available in 10 seconds. Thus the response time depends upon the choice and expense of the terminal.

C H A P T E R 6.

S Y S T E M C O N S T R U C T I O N.

With the design established, the system construction can begin. There are two phases to system construction,; 1) system coding and 2) system debugging. The system is built using "structured programming" approach; build one hierarchy level, debug it, then go to the next. These are iterative phases which circumvent the need for a massive final system debugging activity.

6.1. SYSTEM CODING.

The system design is completely specified by the Decision Tables in Appendix C. The construction consists of coding these Decision Tables in the APL Programming language.

There are numerous techniques possible for coding Decision Tables. The method adopted for CAPP takes full advantage of APL's powerful vector manipulation features. Fig.6.1. shows a typical type of table in the CAPP System. In order to set up the condition to test for Class, it is necessary first to set up a vector as follows:

```
X ← 1 2 3 4
```

This vector is then compared with the Class variable using the equal function:

```
X ← Class = X
```

The result of this operation is a vector variable X with a "1" in the vector position where the value was equal to Class and a "0" in the other positions:

```
X : 0 0 1 0
```

The iota function is then used to find the position of this "1":

```
X ← X ⍳ 1
```

The result is "X" equal to "3". A vector is then established, specifying the statement numbers of possible actions.

```
Y ← 7 7 7 9 11
```

The indexing operator is then used to determine the appropriate statement number:

```
Y ← Y [X]
```

The answer returned is "7". The system then executes statement 7 which commands it to execute Table T310.

An important feature of APL is that these operations can be strung together in a few statements as follows:

```
X ← ((Class = (1 2 3 4)) ⍳ 1)
Y ← 7 7 9 11
→ Y ⍳ X
```

The completed Decision Table, coded in APL, is shown in Fig.6.1.

T300 BODY MATERIAL AND PRESSURE

STANDARD MANAGEMENT

SYSTEM ________ DECISION TABLE Analyst ________

Page ____ of ____ Date ________

IF CLASS =	1	2	3	4
DO TABLE	310	310	310	311
RETURN	X	X	X	X

```
     ∇T300[□]∇
   ∇ T300;X;Y
[1]  X← 1 2 3 4
[2]  X←CLASS=X
[3]  X←X⍳1
[4]  Y← 7 7 7 9 11
[5]  Y←Y[X]
[6]  →Y
[7]  T310
[8]  →13
[9]  T311
[10] →13
[11] '
              ERROR TABLE 300'
[12] →TERMINATE
   ∇
```

DECISION TABLE 300.

Fig. 6.1.

All the tables in Appendix C are written in this fashion, using the Structured Programming approach. The first table coded is table T5 of the first hierarchy level. Then Tables T101, T300, T600, T606 and T1000 are coded. At this point the system is executed and tested for errors. Since the tables developed call for lower level tables, i.e. T101 calls for T129, these are coded as follows:

```
    ∇ T129[□]∇
[1] 'GOTO T129 OK'
2 ∇
```

In this way the coding can be verified immediately. The entire system is developed, one level at a time, until the system is complete.

The system dialogue is constructed last. Tables T1 to T4 reside in the first hierarchy level with T5. A hierarchy level is built above this to manage these tables.

The result of the coding are in Appendix D. This construction effort is very straight forward as a result of the use of the Structured Decision Table design methodology.

6.2. SYSTEM VERIFICATION:

Two levels of system verification are performed. The first is the level by level debugging specified by the Structured Programming approach and the second is the final system testing.

The final verification consists of pacing the system through a representative set of design runs with known results from manual methods. This is a useful process since it uncovers various calculation errors, system logic errors, and data entry errors.

The outcome of the system verification stage was a Computer Automated Proposal Preparation System ready for field testing.

CHAPTER 7.

SYSTEM.

7.1. PURPOSE.

With a rapid increase in volume and complexity of design, an urgent need has developed for a better, faster method of preparing control system proposals. Technical analysis, complex design calculations, and procedures, tedious pricing compilations as well as the preparation of documentation consume precious time. The entire procedure from analysis to final proposal may easily consume 60 hours for a complex system. Of this, only 15 hours, or 25 percent, involves technical analysis and control system design establishment. The remaining 75 percent involves routine and time consuming equipment selection procedures and documentation activities.

The Computer Aided Proposal Preparation System (CAPP) is designed to aid the Design Technician in his efforts to overcome the time crunch. It provides the ability to select equipment and prepare proposals interactively at a computer terminal. He must still analyse and determine system requirements; however, once this is done, he enters the variables and obtains results immediately.

7.2. FUNCTIONAL DESCRIPTION.

CAPP is an interactive system of APL functions which provides the user with an automated control valve selection procedure. It is developed for control valve selection because they are the most time consuming items of any control system design procedure. Also, CAPP is intended as a test case to demonstrate the benifits which are possible from automation. However, it is designed so that it can be easily expanded to include entire control system.

CAPP essentially duplicates the present manual valve selection procedures described in Chapter three. The system performs 1) valve class selection, 2) body material and body pressure standard determination, 3) valve sizing, 4) accessories selection and finally 5) system documentation. The class selection procedure chooses the most appropriate type of valve, i.e. valve class, for the service involved. This procedure also establishes the type of fluid involved. The second procedure consults the ASA tables and determines which valve body material and valve pressure standard combination are best suited for the temperature and pressure of the process. The sizing procedure performs calculations which yield valve size information. Procedure number four currently selects the appropriate valve actuator. This procedure can be expanded to include additional valve accessories. With the valve selection now complete, system documentation, which consists of price make-up sheets and specification sheets, is prepared. Due to its confidential nature, the price determination section has not been included. However, the system design allows it to be easily included at some future date.

7.3. SYSTEM FEATURES.

7.3.1. Duplication.

CAPP functionally duplicates the present valve selection method described in Chapter three. After analysing process system requirements, the design technician enters these into CAPP via a terminal keyboard. CAPP will then perform the equipment selection and proposal preparation.

7.3.2. User Flexibility.

CAPP has been designed so that the user may enter the system wherever he desires. For example, the user may decide to enter at procedure four, valve sizing, or procedure five, accessory determination, instead of at procedure one. The only requirement is that he provides the data which would have been a result of previous procedures.

7.3.3. Sensitivity Analysis.

CAPP provides the ability to perform numerous designs, very quickly, so that the effect of changing one or more input conditions may be determined. For instance, a Valve Capacity/Price ratio, or other type of ratio may be easily determined.

7.3.4. Design Flexibility.

CAPP allows the user to change his mind. If he decides part way through a session that he wishes to change a previously entered input variable, he may do so.

7.3.5. Design Information.

The user may obtain a listing of the values of all internal system variables used in the selection procedure.

7.3.6. Effective Dialogue.

CAPP requests input information in a very natural manner. It instructs the user as to what variable is required and what the appropriate units are. The system also checks the values entered, to see that they are within allowable limits.

If not, it prints an output message and allows the user two additional tries.

7.3.7. Instructions.

During its sign-on procedure, CAPP offers to the user a choice from a number of instruction messages. These messages provide details about the system description, operation, input variables as well as a sample session.

7.3.8. Accuracy.

All system calculations are three decimal places or better.

7.3.9. Maintainability.

The structured program design assures easy maintainability and future expandability. Changes are usually limited to seperate functions, and additional functions are easily added.

7.3.10. Security.

Security is provided by the need for a user number and password before the system can be entered. Also, there is a file security code so that programs can't be changed. Additional security is afforded by the need of an APL terminal, to modify the system. The user will be provided only with a ASCII terminal.

7.3.11. System Output.

The CAPP system provides system output in a form very similar to that produced by manual methods. The quality of the output is depended upon the quality of its output terminal used.

7.4. SYSTEM CHARACTERISTICS.

7.4.1. Structure.

The CAPP system is designed based on a structured programming methodology. This method provides for levels of hierarchy, each containing a number of functional modules. The control between modules is limited to concatenation, iteration and branch upon condition operations.

7.4.2. Documentation.

The system is completely described via Decision Tables. There are a total of fifty tables in the system. These tables operate among fifty multi-branch conditions and 120 actions.

7.4.3. Language.

The system is completely coded in APL programming language.

7.4.4. Functions.

There are fifty functions which make up the entire system. There is a one to one conversion for Decision Tables to APL functions.

7.4.5. Memory.

The system occupies 29K bytes of an APL workspace.

7.4.6. Response Time.

A typical session requires approximately five minutes from sign-on to final system documentation. The manual performance of the same functions requires approximately fifty minutes. The response time from system input to request of next variable is typically three seconds.

7.4.7. Implementation.

The system operates under conventional APL/360. It can operate under any Time-Sharing implementation which supports this language. It requires at least a 32K bytes workspace.

7.4.8. Terminal.

The system has been designed to operate with any standard alphanumeric keyboard type computer terminal. The nature of the system output, however, requires hardcopy capability.

7.5. FUNCTIONS.

A complete list of the Decision Tables which constitute the system is in Appendix C. The equivalent APL functions are in Appendix D.

7.6. USERS' MANUAL.

There are two categories of system operating instructions: 1) system sign-on instructions and 2) system operating instructions.

7.6.1. System Sign-On.

The CAPP system operates on a remote Time-Sharing Computer facility. It is necessary to establish communications with this facility. The sign-on procedure consists of:

1. Turn on the acouster coupler and the computer terminal. Place the terminal in "on-line" operation. Refer to the terminal operating instructions.
2. Using a conventional telephone set, dial up the Time-Sharing service computer number. Upon receipt of the computer tone, plug the telephone head-set into the acouster coupler.
3. It is now necessary to enter the system user number. This is accomplished from the terminal keyboard as follows:

   The system responds with:

   *MCGILL - MUSIC - SIGN ON

4. The system password is now entered as follows:

   The system response is:

```
[redacted]
*IN PROGRESS
*SIGN ON  WED SEP 26, 1973  TIME=21.09  PORT=072  RESTART=083
*GO
/EX APLX1 ******
*IN PROGRESS

music/apl
```

Communication has now been established with the Time-Sharing facility.

7.6.2. System Operation.

A unique feature of CAPP is that the users' manual is an integral part of the system dialogue.

7.6.2.1. Introduction. The CAPP system must now be loaded. This is accomplished as follows:

a) For an APL terminal:

) LOAD KUKI CR

b) For an ASCII terminal:

'" LOAD KUKI CR

In order to initiate CAPP, type:

START

The response is:

```
START

COMPUTER ASSISTED PROPOSAL PREPARATION
                  FOR
          CLASS 1, 2, 3 VALUES
        * VERSION 1 * MAY 1973 *

             MODE SELECTION
             **************
FOR SYSTEM DESCRIPTION TYPE              :T1
FOR OPERATION DESCRIPTION TYPE           :T2
FOR LIST OF INPUT VARIABLES TYPE         :T3
FOR SAMPLE RUN TYPE                      :T4
FOR EXECUTION TYPE                       :T5
FOR TERMINATION TYPE                     :TERMINATE

      ENTER MODE
⎕:
```

7.6.2.2. Systems Modes:

T1

SYSTEM DESCRIPTION
****

THE PURPOSE OF A COMPUTER ASSISTED PROPOSAL PREPARATION SYSTEM , CAPP , IS TO PROVIDE AN EFFICIENT MEANS OF PREPARING CONTROL SYSTEM VALUE PROPOSALS. THE USER WILL ANALYSE AND INTERPRET THE CUSTOMER SPECIFICATIONS AND DEFINE THE SERVICE CONDITIONS AFFECTING THE EQUIPMENT SELECTION. USING THESE CONDITIONS AS INPUTS, CAPP WILL THEN PERFORM EQUIPMENT SELECTION AND PROVIDE A PRINTOUT OF EQUIPMENT DOCUMENTATION AND PRICING.

ENTER MODE

□:

T2

SYSTEM OPERATION
****

CAPP IS DESIGNED WITH USER CONVIENCE IN MIND. USING THE SYSTEM SIMPLY CONSISTS OF PROVIDING ANSWERS TO THE QUESTIONS ASKED. THE SYSTEM CHECKS THE VALUES ENTERED TO VERIFY THAT THEY ARE WITHIN ALLOWABLE LIMITS. A COMPLETE LIST OF SYSTEM VARIABLES IS GIVEN IN MODE T3, AND A SAMPLE SESSION IS GIVEN IN MODE T4. REFER TO THE SYSTEM USERS MANUAL FOR A COMPLETE DESCRIPTION OF SYSTEM OPERATION.

ENTER MODE

□:

T3

SYSTEM VARIABLES

INPUT VARIABLES

SYMBOL	DESCRIPTION	FUNCTION	UNITS
SERV	VALVE SERVICE	T101	1:ATOMIZING STEAM SHUT OFF 2:BOILER AUXILLIARIES 3:DESUPERHEATER WATER SPRAY 4:FEEDWATER FLOW 5:HEATER LEVEL CONTROL 6:OIL SHUT OFF 7:OIL BURNER CONTROL 8:PUMP RECIRC SHUT OFF 9:SUPERHEATER SPRAY CONTROL 10:REHEAT SPRAY CONTROL 11:SUPERHEATER SPRAY SHUT OFF 12:REHEAT SPRAY SHUT OFF 13:STEAM PRESSURE REDUCING
T	FLUID TEMPERATURE	T101	DEGREES F
PA	STATIC INLET PRESSURE	T129	PSIA
PD	PRESSURE DROP	T600	PSI
VIS	VISCOSITY	T604	SSU
W	MAX VALVE CAPACITY(LIQ)	T605	LBS/HR
SPC	SPECIFIC GRAVITY(LIQ)	T605	
Q	MAX VALVE CAPACITY(GAS)	T605	SCHF
G	SPECIFIC GRAVITY(GAS)	T605	
VLVPOS	VALVE POSITION	T606	NO:NORMALLY OPEN NC:NORMALLY CLOSED

```
T4
                SAMPLE SESSION
                **************

FOR A COMPLETE EXAMPLE OF A SYSTEM SESSION REFER TO
THE CAPP USERS MANUAL


        ENTER MODE
□:
       TERMINATE
THIS SESSION IS TERMINATING ; TO RESTART TYPE START OR ENTER MODE
```

```
TS
ENTER SERVICE
□:
       01

        ENTER STATIC INLET PRESSURE; PSIA
□:
       600

        ENTER TEMPERATURE; OF
□:
       486
ENTER PRESSURE DROP ; PSI
□:
       200
ENTER MAXIMUM VALVE CAPACITY; LBS/HR
□:
       10000
ENTER SPECIFIC VOLUME ; CU FT/LBS
□:
       .7790
```

T1200

VALVE SPECIFICATIONS
****

ITEM NUMBER: QUANTITY:
SERVICE:5

BODY SIZE :1 INS
CLASS :1
FLUID :4
CAPACITY :10000 LBS/HR 0 SCHF
INLET PRES :600 PSIA
PRES DROP :200 PSI
TEMPERATURE :468 DEGREES F
SP GRAVITY :1

BODY PRESSURE STANDARD:1500
BODY MATERIAL :1
ACTUATOR SIZE :60

ACCESSORIES:

SHIPPING WGT:
AIR CONSUMPTION:
REMARKS:

T1201

VALVE PRICE MAKE UP
****

ITEM NUMBER: QUANTITY:

DESCRIPTION		PRICE
BODY	PRESSURE STANDARD:1500 MATERIAL :1	______
ACTUATOR	SIZE :60	______
ACCESSORIES		______ ______ ______ ______ ______
SHIPPING WEIGHT		
	TOTAL PRICE	______
	* QUANTITY	______

7.6.2.3. Standard Session: An example of a standard session is shown by entering mode T5.

7.6.2.4. Introduction Suppression: By entering the desired mode, i.e: T5, instead of entering START, the system introduction may be suppressed.

7.6.2.5. System Flexibility: The system can commence at any function simply by entering the function name:

T300

```
T600
ENTER PRESSURE DROP : PSI
⎕:
      1400
```

It is necessary to have a thorough familiarization with the Decision Tables in Appendix C and APL functions in Appendix D, before this feature can be effectively employed.

7.6.2.6. Process Flexibility: If the user decides part way through a session that he wishes to change a previously entered input variable, he may do this by entering the name of the function which requests the variable:

```
T5
ENTER SERVICE
□:
      1
ENTER STATIC INLET PRESSURE : PSIA
□:
      1400
ENTER TEMPERATURE : OF
□:
      F5
ENTER SERVICE
□:
      2
ENTER STATIC INLET PRESSURE : PSIA
□:
      1400
ENTER TEMPERATURE : OF
□:
      587
ENTER PRESSURE DROP : PSI
□:
```

The more familiar the user is with the system, the more effectively he can use this facility.

7.6.2.7. Design Information: All input variables, internal variables and output variables may be requested simply by typing in the variable name:

```
     SERV
5
     PA
600
     T
468
     PD
200
```

CHAPTER 8.

CONCLUSIONS

8.1 RESUMÉ

The purpose of this thesis is to investigate the applicability of computer techniques to process control system proposal preparation. A complete discussion of the control system environment, explaining design and proposal preparation procedures, is given in Chapter two. A peculiarity of process control systems is that similar proposal preparation procedures are followed for all of them. A representative procedure, control valve proposal preparation, is a good test case for the development of CAPP, a Computer Assisted Proposal Preperation System. The conclusions drawn from this system are used to establish the applicability of computer techniques.

Before a system can be designed and developed, a detailed definition of system requirements is needed. Chapter three provides a complete problem description in the form of a list of requirements. The design methodology and procedures, yielding specifications satisfying system requirements, are discussed in Chapter four. System construction activities are described in Chapter five.

The result, described in Chapter six, is CAPP, an automated valve selection procedure. The many benefits displayed by this automated system are applicable to all control systems. The major user criticism of CAPP was that it was only currently available for valve proposals. This system also provides valuable design experience for future system development.

The available benefits and user reaction establish, beyond any doubt, the applicability of computer assisted techniques to process control system proposal preparation.

8.2. BENEFITS.

Of the control system design activities described in Chapter two, proposal preparation may be the least significant in terms of sophistication, but it certainly is not in terms of volume. An instrument company must perform this selection and pricing for each set of specifications for which it submits a bid. Over a number of years, the amount of time and money spent on this activity may easily surpass that spent at the control system research and development stage. Therefore, the benefits possible from automation are important. CAPP demonstrates these benefits in terms of performance improvements and cost savings. These benefits are applicable to all types of control systems.

8.2.1. Performance Benefits.

Many of the benefits available to an instrument company from a Computer Assisted Design system cannot be given a direct monetary value. Nevertheless, their importance warrants consideration. Some of the benefits demonstrated by CAPP are:

1. Optimization of Equipment Selection. The system design incorporates a number of controls to optimize equipment selection in accordance with the definition of system requirements: example, minimum cost, delivery, inventories.

2. Sensitivity Analysis. An automated system provides a means of determining the sensitivity of the equipment type selected to variations in service conditions, i.e. effect of a change in boiler capacity on a valve size selected and hence the price. This is important since many service conditions are estimated.

3. Operator Guidance. By requesting the operator to supply a complete set of input data before it will proceed, as well as verifying the rationality of these inputs, an automated procedure assists the operator in defining the service conditions.

4. Competitive Advantage. An automated system provides the Company with a competitive advantage by maintaining a number of overhead costs static while increasing productivity.

5. Consistency of Equipment Selection. The system ensures that equipment would be selected on the basis of pre-defined criteria and would not be subject to personal bias.

6. Quality of Documentation. Once equipment selection has been completed, the automated system extracts data associated with that piece of equipment, and provides a print-out of this data for engineering analysis, pricing and/or listing equipment. Both input and output data would be documented in a consistent acceptable format.

7. Efficiency. By mechanizing and thereby accelerating tasks, the system allows for more efficient use of technical expertise available.

8. Accuracy. When calculations are necessary for equipment selection, an automated system provides accuracy of a much higher order than sliderule computations.

9. Management Information. An important aspect of a computer based system is its ability to provide Management with organized information relating to internal operations. For example, data files that are established, such as factors for determining cost of sales, can be made readily available.

10. Inter-Departmental Benefits. The system can expand to perform various other activities within the Company, i.e. cost of Sales Analysis, Engineering Department SO documentation and purchase requisition documentation, etc.

11. Man-Hour Reduction. As demonstrated by CAPP, an automated procedure requires approximately ten percent of the time the manual procedure required to perform the same function.

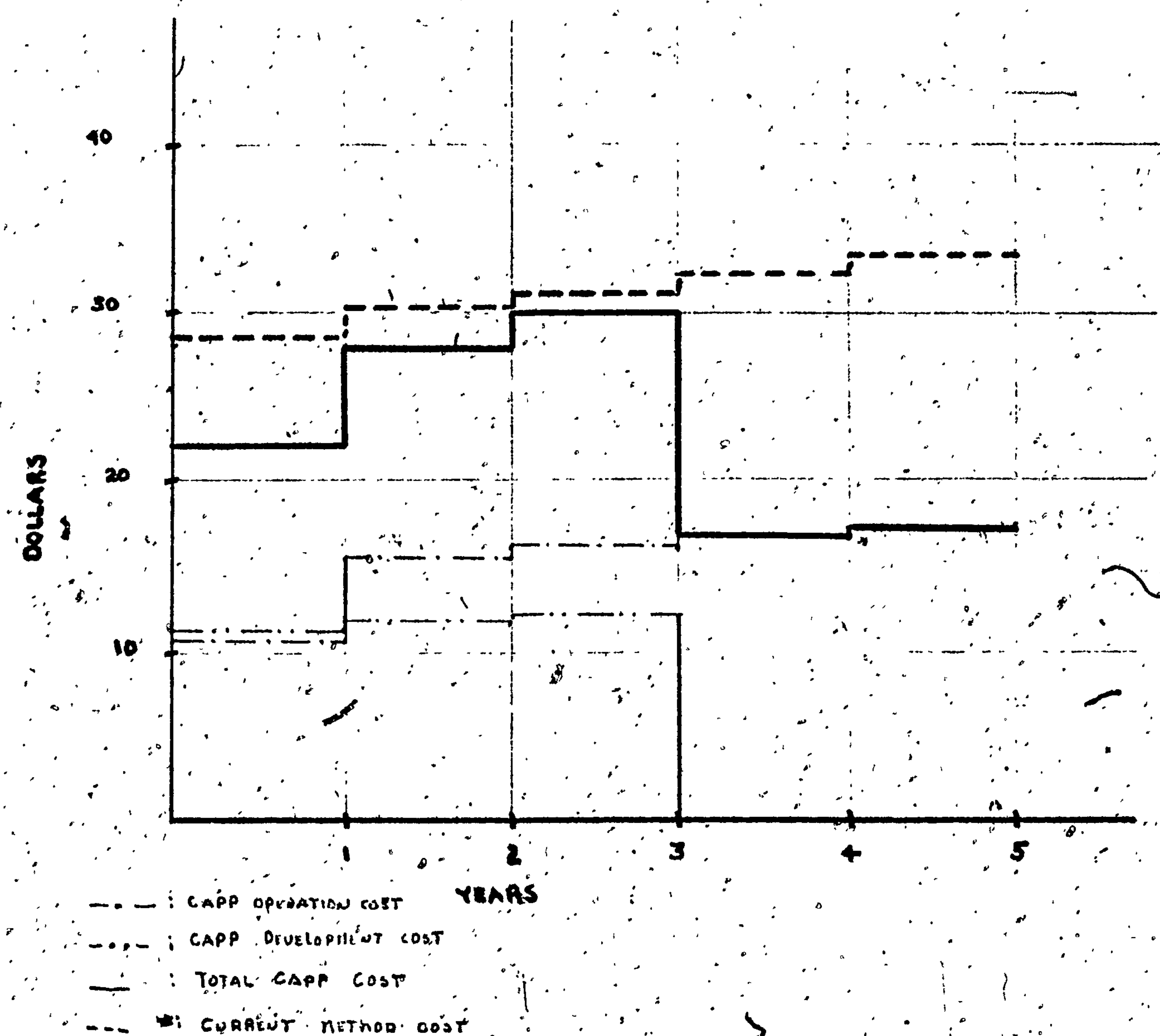
12. System Documentation. The entire valve sizing procedure is well documented in the form of Decision Tables. This provides a convenient training document in valve selection procedures.

13. System Modification. Any modifications to the valve selection procedures may be easily recorded due to the Decision Table type of documentation.

8.2.2. Economic Benefits.

A detailed cost analysis reveals a significant saving available through the automation of the proposal preparation activities of an instrument company. By extrapolating the results obtained by CAPP, it was concluded that a fifteen percent saving of current costs is possible in the first three years, with a fifty percent saving possible for each year thereafter. The cost saving for a single control system is illustrated in Fig.8.1. For the typical instrument company, which offers five types of control systems, this translates into approximately a $60,000.00 saving over the first three years, and a $80,000.00 a year saving thereafter. Details of this cost analysis are in Appendix F.

COST ANALYSIS
FOR ONE CONTROL SYSTEM TYPE.



Cost Analysis
Fig.8.1.

8.3. USER REACTION.

Although it is intended to perform a lengthly field evaluation of CAPP, user exposure to date has been limited to brief demonstrations. Nevertheless, user reaction is very favourable. The major criticism was its current unavailability for all control system proposal preparation procedures. Initial reaction to the system is as follows:

8.3.1. Speed.

Users are impressed with the systems speed and simplicity of operation.

8.3.2. Dialogue.

The users appreciate the system prompting and assisting when entering input variables. However, they express a desire for a short-cut type of entry method for use after becoming familiar with the system.

8.3.3. Documentation.

The users desire an output graphic capability in order that output forms may exactly duplicate present forms. This is possible with a Tektronix 4013 or 4023 terminal. However, it increases the operating cost of the system.

8.3.4. Accuracy.

Initially the users doubt the accuracy of the system. This is soon dispelled after manual verification of the system results.

8.4. DESIGN CONCLUSIONS.

It makes good sense to develop a prototype system to test out a concept, before evaluating large amounts of time and money developing an entire system. CAPP is designed as a test case to evaluate the concept of automation of control system proposal preparation procedures.

Much insight concerning system design requirements and needs are demonstrated by CAPP. The design methodology is tested. Also, it provides a means of using hind-sight to determine what should be done before and during design stages in order to optimize results.

Design conclusions resulting from CAPP are as follows:

8.4.1. Structured Decision Tables.

The choice of decision tables as a means of system documentation is excellent. The tables provide accurate logic definitions, and they are easy to prepare and use. The nature of decision table modules is well suited to the structured Decision Table programming methodology of the system.

8.4.2. Structured Programming.

Structured Programming is an excellent design methodology. The systematic, level by level, design and development approach prevents most logic errors from occuring. The limitation to only three permissable control structures; concatenation, iteration, and selection based on the testing of a condition allow for predictable flow of control. This results in easy detection of any remaining logic errors. These simple control structures also enhance the benefits available through modularization. Additional benefits such as reliability, readability as well as easy maintainability and expansions result from structured programming.

8.4.3. APL Programming Language.

The power and ease of use of APL makes its suitability obvious. The disadvantages of APL are its requirement for CPU time and core storage. The CPU time expense however is compensated by the development time saved as a result of its power. The expensive use of core storage can be overcome by concentrating on more efficient coding when developing future systems.

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APPENDIX A.

CURRENT VALVE SELECTION PROCEDURE.

A.1. SYSTEM INPUTS.

When selecting a control or shut-off valve, the following input information about the process is required:

1. Kind of Service. The services available to choose from are:

   Service 1: Atomizing Steam Shut-Off
   Service 2: Boiler Auxiliaries
   Service 3: Desuperheater Water Spray
   Service 4: Feedwater Flow
   Service 5: Heater Level Control
   Service 6: Oil Shut-Off
   Service 7: Oil Burner Control
   Service 8: Pump Recirculation Shut-Off
   Service 9: Superheater Spray Water Control
   Service 10: Reheat Spray Water Control
   Service 11: Superheat Spray Water Shut-Off
   Service 12: Reheat Spray Water Shut-Off
   Service 13: Steam Pressure Reducing

2. Operating Conditions of process fluid:

   a. Static Inlet Pressure (PSIA)
   b. Pressure Drop
   c. Viscosity (SSU)
   d. Maximum Valve Capacity (lbs./hr. or $ft.^3$/hr.)
   e. Specific Weight (lbs/$ft.^3$)
   f. Specific Gravity
   g. Specific Volume

3. Movement of valve on failure of actuating medium (normally open or normally closed).

A.2. VALVE CLASS SELECTION.

A.2.1. Valve Class Selection Based on Service.

The following table provides the general recommendations for the most commonly encountered services.

Table A.1. Class Selection.

Service	Valve Class	
	1st.choice	2nd.choice
1. Atomizing Steam Shut-Off	1	-
2. Boiler Auxiliaries	2	-
3. Desuperheater Water Spray	2	3
4. Feedwater Flow	4	-
5. Heater Level Control	4	-
6. Oil Shut-Off	1	-
7. Oil Burner Control	2	-
8. Pump Recirculation Shut-Off	1	-
9. Superheat Spray Water Control	2	3
10. Reheat Spray Water Control	2	3
11. Superheat Spray Water Shut-Off	1	-
12. Reheat Spray Water Shut-Off	1	-
13. Steam Pressure Reducing	2	4

A.2.2. Fluid Determination Based on Service.

Once the valve class is chosen, the process fluid is decided on depending upon the service as follows:

Table A.2. Fluid Selection.

Service	Fluid
1. Atomizing Steam Shut-Off	Steam
2. Boiler Auxiliaries	Steam
3. Desuperheater Water Spray	Liquid
4. Feedwater Flow	Liquid
5. Heater Level Control	Liquid
6. Oil Shut-Off	Oil
7. Oil Burner Control	Oil
8. Pump Recirculation Shut-Off	Liquid
9. Superheat Spray Water Control	Liquid
10. Reheat Spray Water Control	Liquid
11. Superheat Spray Water Shut-Off	Liquid
12. Reheat Spray Water Shut-Off	Liquid
13. Steam Pressure Reducing	Steam

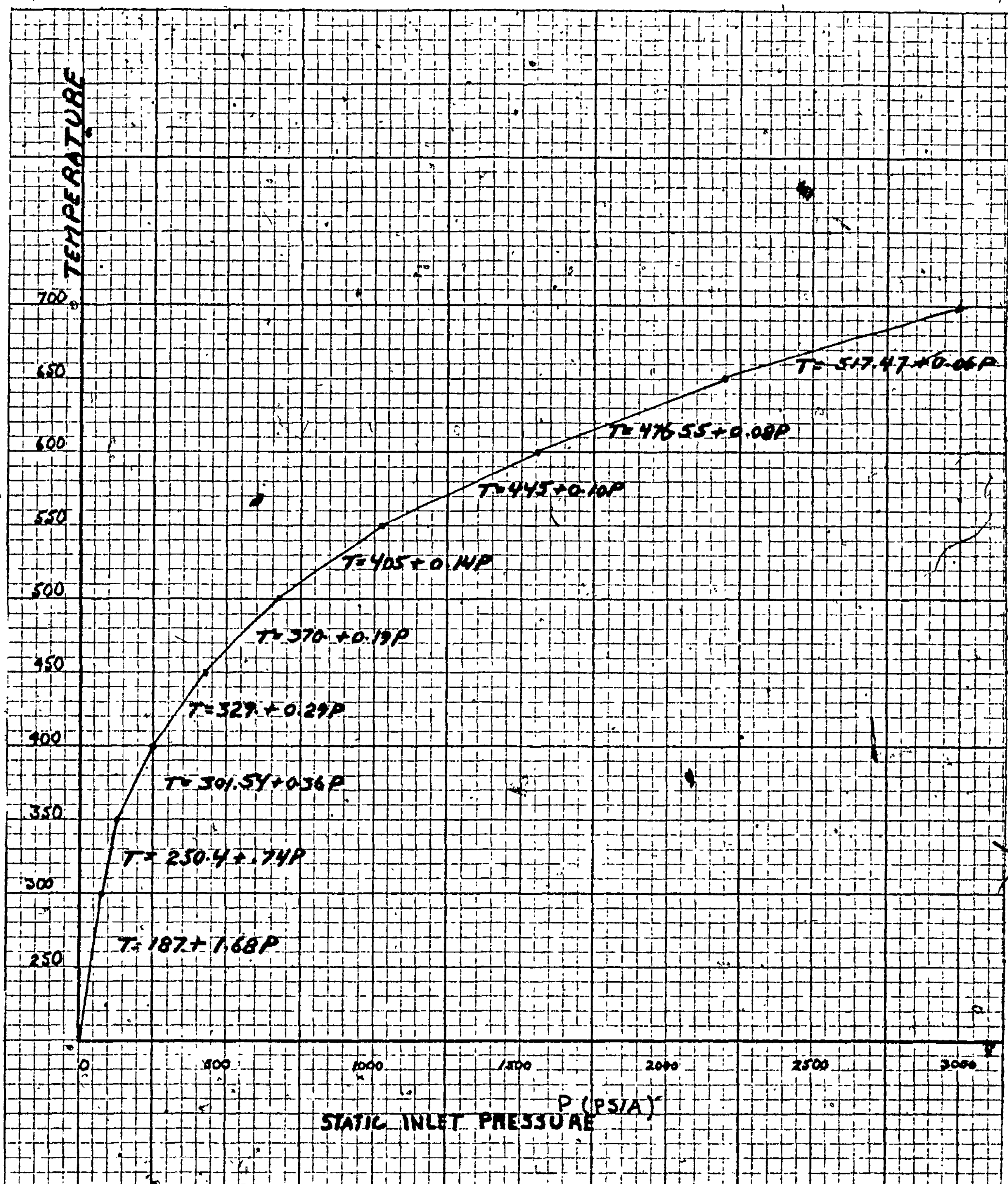
A.2.3. Sizing Coefficient and Quality of Steam.

A valve sizing coofficient is then chosen from the following table.

Table A.3. Sizing Coefficient.

Valve Class	Coefficient F
Class 1	.65
Class 2.	.65
Class 3	.65
Class 4 (liquid)	.5
Class 4 (steam)	.5

For steam services, the quality of the process steam must now be determined. This consists of consulting Fig.A.1 to determine if the steam is 1) Superheated Steam, 2) Dry Superheated Steam or 3) Wet Superheated Steam. The curve in Fig.A.1 was derived from steam tables.



QUALITY OF STEAM
Fig. A.1.

TABLE A.4 STEAM TABLES

Absolute Pressure = atmospheric pressure − vacuum.
Barometer and vacuum columns may be corrected to mercury at 32°F. by subtracting, 0.00009 × $(t - 32)$ × column height, where t is the column temperature in °F.
1 inch of mercury at 32°F. = 0.4912 lb./sq. in.

Example: Barometer reads 30.17 inches at 70°F. Vacuum column reads 28.26 inches at 80°F. Abs. press. = (30.17 − 0.00009 × 38 × 30.17) − (28.26 − 0.00009 × 48 × 28.26) = 1.93 inches of mercury at 32°F.
Saturation temperature (from table) = 100°F.

Table 1. Saturated Steam: Temperature Table

Temp. Fahr. t	Absolute Pressure: Lb. per Sq. In. p	Absolute Pressure: In. Hg 32 F.	Specific Volume: Sat. Liquid v_f	Specific Volume: Evap. v_{fg}	Specific Volume: Sat. Vapor v_g	Enthalpy: Sat. Liquid h_f	Enthalpy: Evap. h_{fg}	Enthalpy: Sat. Vapor h_g	Entropy: Sat. Liquid s_f	Entropy: Evap. s_{fg}	Entropy: Sat. Vapor s_g	Temp. Fahr. t
32	0.0886	0.1806	0.01602	3305.7	3305.7	0	1075.1	1075.1	0	2.1865	2.1865	32
34	0.0961	0.1957	0.01602	3060.4	3060.4	2.01	1074.0	1076.0	0.0041	2.1755	2.1796	34
36	0.1041	0.2120	0.01602	2836.6	2836.6	4.03	1072.9	1076.9	0.0082	2.1645	2.1727	36
38	0.1126	0.2292	0.01602	2632.2	2632.2	6.04	1071.7	1077.7	0.0122	2.1533	2.1655	38
40	0.1217	0.2478	0.01602	2445.1	2445.1	8.05	1070.5	1078.6	0.0162	2.1423	2.1585	40
42	0.1315	0.2677	0.01602	2271.8	2271.8	10.06	1069.3	1079.4	0.0203	2.1314	2.1517	42
44	0.1420	0.2891	0.01602	2112.2	2112.2	12.06	1068.2	1080.3	0.0242	2.1207	2.1449	44
46	0.1532	0.3119	0.01602	1965.5	1965.5	14.07	1067.1	1081.2	0.0282	2.1102	2.1384	46
48	0.1652	0.3364	0.01602	1829.9	1829.9	16.07	1065.9	1082.0	0.0322	2.0995	2.1317	48
50	0.1780	0.3624	0.01602	1704.9	1704.9	18.07	1064.8	1082.9	0.0361	2.0891	2.1252	50
52	0.1918	0.3905	0.01603	1588.4	1588.4	20.07	1063.6	1083.7	0.0400	2.0786	2.1186	52
54	0.2063	0.4200	0.01603	1482.4	1482.4	22.07	1062.5	1084.6	0.0439	2.0684	2.1123	54
56	0.2219	0.4518	0.01603	1383.5	1383.5	24.07	1061.4	1085.5	0.0478	2.0582	2.1060	56
58	0.2384	0.4854	0.01603	1292.7	1292.7	26.07	1060.2	1086.3	0.0517	2.0479	2.0996	58
60	0.2561	0.5214	0.01603	1208.1	1208.1	28.07	1059.1	1087.2	0.0555	2.0379	2.0934	60
62	0.2749	0.5597	0.01604	1129.7	1129.7	30.06	1057.9	1088.0	0.0594	2.0278	2.0872	62
64	0.2949	0.6004	0.01604	1057.1	1057.1	32.06	1056.8	1088.9	0.0632	2.0180	2.0812	64
66	0.3162	0.6438	0.01604	989.6	989.6	34.06	1055.7	1089.8	0.0670	2.0082	2.0752	66
68	0.3388	0.6898	0.01605	927.0	927.0	36.05	1054.5	1090.6	0.0708	1.9983	2.0691	68
70	0.3628	0.7387	0.01605	868.9	868.9	38.05	1053.4	1091.5	0.0745	1.9887	2.0632	70
72	0.3883	0.7906	0.01606	814.9	814.9	40.04	1052.3	1092.3	0.0783	1.9792	2.0575	72
74	0.4153	0.8456	0.01606	764.7	764.7	42.04	1051.2	1093.2	0.0820	1.9697	2.0517	74
76	0.4440	0.9040	0.01607	718.0	718.0	44.03	1050.1	1094.1	0.0858	1.9603	2.0461	76
78	0.4744	0.9659	0.01607	674.4	674.4	46.03	1048.9	1094.9	10.0895	.9508	2.0403	78
80	0.5067	1.032	0.01607	633.7	633.7	48.02	1047.8	1095.8	0.0932	1.9415	2.0347	80
82	0.5409	1.101	0.01608	595.8	595.8	50.02	1046.6	1096.6	0.0969	1.9321	2.0290	82
84	0.5772	1.175	0.01608	560.4	560.4	52.01	1045.5	1097.5	0.1006	1.9230	2.0236	84
86	0.6153	1.253	0.01609	527.6	527.6	54.01	1044.4	1098.4	0.1042	1.9139	2.0181	86
88	0.6555	1.335	0.01609	497.0	497.0	56.00	1043.2	1099.2	0.1079	1.9047	2.0126	88
90	0.6980	1.421	0.01610	468.4	468.4	58.00	1042.1	1100.1	0.1115	1.8958	2.0073	90
92	0.7429	1.513	0.01611	441.7	441.7	59.99	1040.9	1100.9	0.1151	1.8867	2.0018	92
94	0.7902	1.609	0.01611	416.7	416.7	61.98	1039.8	1101.8	0.1187	1.8779	1.9966	94
96	0.8403	1.711	0.01612	393.2	393.2	63.98	1038.7	1102.7	0.1223	1.8692	1.9915	96
98	0.8930	1.818	0.01613	371.3	371.3	65.98	1037.5	1103.5	0.1259	1.8604	1.9863	98
100	0.9487	1.932	0.01613	350.8	350.8	67.97	1036.4	1104.4	0.1295	1.8517	1.9812	100
102	1.0072	2.051	0.01614	331.5	331.5	69.96	1035.2	1105.2	0.1330	1.8430	1.9760	102
104	1.0689	2.176	0.01614	313.5	313.5	71.96	1034.1	1106.1	0.1366	1.8345	1.9711	104
106	1.1338	2.308	0.01615	296.5	296.5	73.95	1033.0	1107.0	0.1401	1.8261	1.9662	106
108	1.2020	2.447	0.01616	280.7	280.7	75.94	1032.0	1107.9	0.1436	1.8179	1.9615	108
110	1.274	2.594	0.01617	265.7	265.7	77.94	1030.9	1108.8	0.1471	1.8096	1.9567	110
112	1.350	2.749	0.01617	251.6	251.6	79.93	1029.7	1109.6	0.1506	1.8012	1.9518	112
114	1.429	2.909	0.01618	238.5	238.5	81.93	1028.6	1110.5	0.1541	1.7930	1.9471	114
116	1.512	3.078	0.01619	226.2	226.2	83.92	1027.5	1111.4	0.1576	1.7848	1.9424	116
118	1.600	3.258	0.01620	214.5	214.5	85.92	1026.4	1112.3	0.1610	1.7767	1.9377	118
120	1.692	3.445	0.01620	203.46	203.47	87.91	1025.3	1113.2	0.1645	1.7687	1.9332	120
122	1.788	3.640	0.01621	193.16	193.18	89.91	1024.1	1114.0	0.1679	1.7606	1.9285	122
124	1.889	3.846	0.01622	183.44	183.46	91.90	1023.0	1114.9	0.1714	1.7526	1.9240	124
126	1.995	4.062	0.01623	174.26	174.28	93.90	1021.8	1115.7	0.1748	1.7446	1.9194	126
128	2.105	4.286	0.01624	165.70	165.72	95.90	1020.7	1116.6	0.1782	1.7368	1.9150	128
130	2.221	4.522	0.01625	157.55	157.57	97.89	1019.5	1117.4	0.1816	1.7289	1.9105	130
132	2.343	4.770	0.01626	149.83	149.85	99.89	1018.3	1118.2	0.1849	1.7210	1.9059	132
134	2.470	5.029	0.01626	142.59	142.61	101.89	1017.2	1119.1	0.1883	1.7134	1.9017	134
136	2.603	5.300	0.01627	135.73	135.75	103.88	1016.0	1119.9	0.1917	1.7056	1.8973	136
138	2.742	5.583	0.01628	129.26	129.28	105.88	1014.9	1120.8	0.1950	1.6980	1.8930	138
140	2.887	5.878	0.01629	123.16	123.18	107.88	1013.7	1121.6	0.1984	1.6904	1.8888	140
142	3.039	6.187	0.01630	117.37	117.39	109.88	1012.5	1122.4	0.2017	1.6828	1.8845	142
144	3.198	6.511	0.01631	111.88	111.90	111.88	1011.3	1123.2	0.2050	1.6752	1.8802	144
146	3.363	6.847	0.01632	106.72	106.74	113.88	1010.2	1124.1	0.2083	1.6678	1.8761	146
148	3.536	7.199	0.01633	101.82	101.84	115.87	1009.0	1124.9	0.2116	1.6604	1.8720	148

Temp. Fahr. t	Absolute Pressure		Specific Volume			Enthalpy			Entropy			Temp Fahr. t
	Lb. per Sq. In. p	In. Hg. 32 F.	Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g	
150	3.716	7.566	0.01634	97.18	97.20	117.87	1007.8	1125.7	0.2149	1.6530	1.8679	150
152	3.904	7.948	0.01635	92.79	92.81	119.87	1006.7	1126.6	0.2181	1.6458	1.8639	152
154	4.100	8.348	0.01636	88.62	88.64	121.87	1005.5	1127.4	0.2214	1.6384	1.8598	154
156	4.305	8.765	0.01637	84.66	84.68	123.87	1004.4	1128.3	0.2247	1.6313	1.8560	156
158	4.518	9.199	0.01638	80.90	80.92	125.87	1003.2	1129.1	0.2279	1.6241	1.8520	158
160	4.739	9.649	0.01639	77.37	77.39	127.87	1002.0	1129.9	0.2311	1.6169	1.8480	160
162	4.970	10.12	0.01640	74.00	74.02	129.88	1000.8	1130.7	0.2343	1.6098	1.8441	162
164	5.210	10.61	0.01642	70.79	70.81	131.88	999.7	1131.6	0.2376	1.6029	1.8405	164
166	5.460	11.12	0.01643	67.76	67.78	133.88	998.5	1132.4	0.2408	1.5958	1.8366	166
168	5.720	11.65	0.01644	64.87	64.89	135.88	997.3	1133.2	0.2439	1.5888	1.8327	168
170	5.990	12.20	0.01645	62.12	62.14	137.89	996.1	1134.0	0.2471	1.5819	1.8290	170
172	6.272	12.77	0.01646	59.50	59.52	139.89	995.0	1134.9	0.2503	1.5751	1.8254	172
174	6.565	13.37	0.01647	57.01	57.03	141.89	993.8	1135.7	0.2535	1.5683	1.8218	174
176	6.869	13.99	0.01648	54.64	54.66	143.90	992.6	1136.5	0.2566	1.5615	1.8181	176
178	7.184	14.63	0.01650	52.39	52.41	145.90	991.4	1137.3	0.2598	1.5547	1.8145	178
180	7.510	15.29	0.01651	50.26	50.28	147.91	990.2	1138.1	0.2629	1.5479	1.8108	180
182	7.849	15.98	0.01653	48.22	48.24	149.92	989.0	1138.9	0.2661	1.5412	1.8073	182
184	8.201	16.70	0.01653	46.28	46.30	151.92	987.8	1139.7	0.2692	1.5346	1.8038	184
186	8.566	17.44	0.01654	44.43	44.45	153.93	986.6	1140.5	0.2723	1.5280	1.8003	186
188	8.944	18.21	0.01656	42.67	42.69	155.94	985.3	1141.3	0.2754	1.5213	1.7967	188
190	9.336	19.01	0.01657	40.99	41.01	157.95	984.1	1142.1	0.2785	1.5147	1.7932	190
192	9.744	19.84	0.01658	39.38	39.40	159.95	982.8	1142.8	0.2816	1.5081	1.7897	192
194	10.168	20.70	0.01659	37.84	37.86	161.96	981.5	1143.5	0.2847	1.5015	1.7862	194
196	10.605	21.59	0.01661	36.38	36.40	163.97	980.3	1144.3	0.2877	1.4951	1.7828	196
198	11.057	22.51	0.01662	34.08	35.00	165.98	979.0	1145.0	0.2908	1.4885	1.7793	198
200	11.525	23.46	0.01663	33.65	33.67	167.99	977.8	1145.8	0.2938	1.4822	1.7760	200
202	12.010	24.45	0.01665	32.37	32.39	170.01	976.6	1146.6	0.2969	1.4759	1.7728	202
204	12.512	25.47	0.01666	31.15	31.17	172.02	975.3	1147.3	0.2999	1.4695	1.7694	204
206	13.031	26.53	0.01667	29.99	30.01	174.03	974.1	1148.1	0.3029	1.4633	1.7662	206
208	13.568	27.62	0.01669	28.88	28.90	176.04	972.8	1148.8	0.3059	1.4570	1.7629	208
210	14.123	28.75	0.01670	27.81	27.83	178.06	971.5	1149.6	0.3090	1.4507	1.7597	210
212	14.696	29.92	0.01672	26.81	26.83	180.07	970.3	1150.4	0.3120	1.4446	1.7566	212
215	15.591		0.01674	25.35	25.37	183.10	968.3	1151.4	0.3165	1.4352	1.7517	215
220	17.188		0.01677	23.14	23.16	188.14	965.2	1153.3	0.3239	1.4201	1.7440	220
225	18.915		0.01681	21.15	21.17	193.18	961.9	1155.1	0.3313	1.4019	1.7362	225
230	20.78		0.01684	19.371	19.388	198.22	958.7	1156.9	0.3386	1.3900	1.7286	230
235	22.80		0.01688	17.761	17.778	203.28	955.3	1158.6	0.3459	1.3751	1.7210	235
240	24.97		0.01692	16.307	16.324	208.34	952.1	1160.4	0.3531	1.3607	1.7138	240
245	27.31		0.01696	15.010	15.027	213.41	948.7	1162.1	0.3604	1.3462	1.7066	245
250	29.82		0.01700	13.824	13.841	218.48	945.3	1163.8	0.3675	1.3320	1.6995	250
255	32.53		0.01704	12.735	12.752	223.56	942.0	1165.6	0.3747	1.3181	1.6928	255
260	35.43		0.01708	11.754	11.771	228.65	938.6	1167.3	0.3817	1.3042	1.6859	260
265	38.54		0.01713	10.861	10.878	233.74	935.3	1169.0	0.3888	1.2906	1.6794	265
270	41.85		0.01717	10.053	10.070	238.84	931.8	1170.6	0.3958	1.2770	1.6728	270
275	45.40		0.01721	9.313	9.330	243.94	928.2	1172.1	0.4027	1.2634	1.6661	275
280	49.20		0.01726	8.634	8.651	249.06	924.6	1173.7	0.4096	1.2500	1.6596	280
285	53.25		0.01731	8.015	8.032	254.18	921.0	1175.2	0.4165	1.2368	1.6533	285
290	57.55		0.01735	7.448	7.465	259.31	917.4	1176.7	0.4234	1.2237	1.6471	290
295	62.13		0.01740	6.931	6.948	264.45	913.7	1178.2	0.4302	1.2107	1.6409	295
300	67.01		0.01745	6.454	6.471	269.60	910.1	1179.7	0.4370	1.1980	1.6350	300
305	72.18		0.01750	6.014	6.032	274.76	906.3	1181.1	0.4437	1.1852	1.6289	305
310	77.68		0.01755	5.610	5.628	279.92	902.6	1182.5	0.4505	1.1727	1.6232	310
315	83.50		0.01760	5.239	5.257	285.10	898.8	1183.9	0.4571	1.1587	1.6158	315
320	89.65		0.01765	4.897	4.915	290.29	895.0	1185.3	0.4637	1.1479	1.6116	320
325	96.16		0.01771	4.583	4.601	295.49	891.1	1186.6	0.4703	1.1356	1.6059	325
330	103.03		0.01776	4.292	4.310	300.69	887.1	1187.8	0.4769	1.1234	1.6003	330
335	110.31		0.01782	4.021	4.039	305.91	883.2	1189.1	0.4835	1.1114	1.5949	335
340	117.99		0.01788	3.771	3.789	311.14	879.2	1190.3	0.4900	1.0994	1.5894	340
345	126.10		0.01793	3.539	3.557	316.38	875.1	1191.5	0.4966	1.0875	1.5841	345
350	134.62		0.01799	3.324	3.342	321.64	871.0	1192.6	0.5030	1.0757	1.5787	350
355	143.58		0.01805	3.126	3.144	326.91	866.8	1193.7	0.5094	1.0640	1.5734	355
360	153.01		0.01811	2.940	2.958	332.19	862.5	1194.7	0.5159	1.0522	1.5681	360
365	162.93		0.01817	2.768	2.786	337.48	858.2	1195.7	0.5223	1.0406	1.5629	365
370	173.33		0.01823	2.607	2.625	342.79	853.8	1196.6	0.5286	1.0291	1.5577	370
375	184.23		0.01830	2.458	2.476	348.11	849.4	1197.5	0.5350	1.0176	1.5526	375
380	195.70		0.01836	2.318	2.336	353.45	844.9	1198.4	0.5413	1.0062	1.5475	380
385	207.71		0.01843	2.189	2.207	358.80	840.4	1199.2	0.5476	0.9949	1.5425	385

A.3. BODY SELECTION.

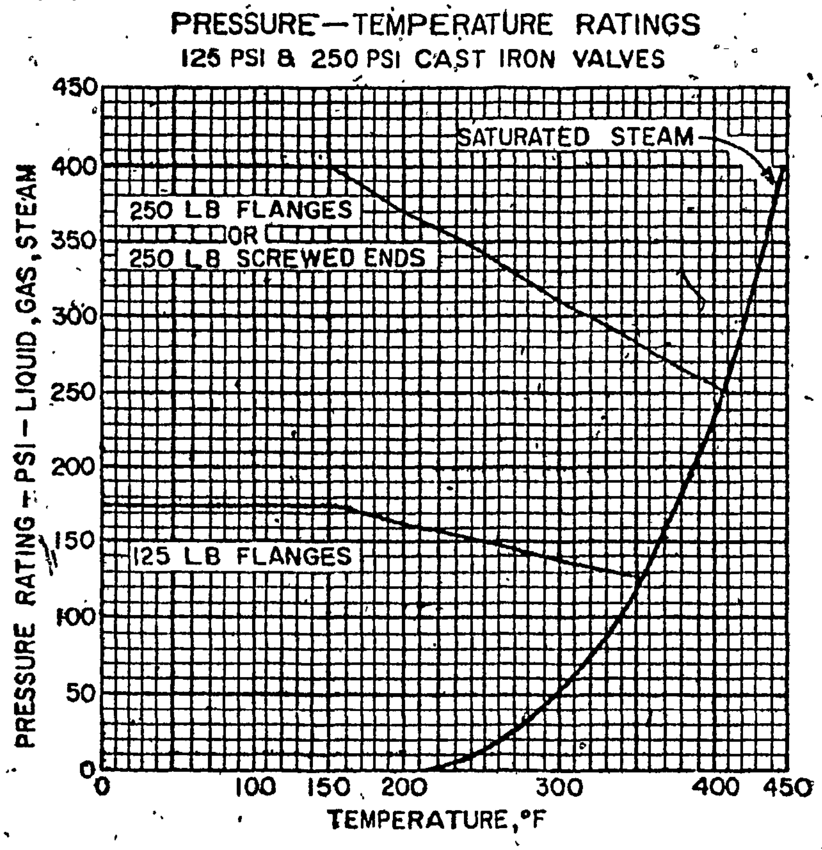
Since control valves are called upon to handle all kinds of fluids from clean, dry air to corrosive chemicals, at service temperatures from near absolute to well above 1000F, and pressures from near vacumm to 50,000 PSIG or higher, proper selection of valve body material is of the utmost importance. Since the majority of applications are non-corrosive and at reasonable pressures and temperatures, cast iron and carbon steel are the most common body materials. The materials available for the valve classes considered are as follows:

Table A.5 Valve Body Choice.

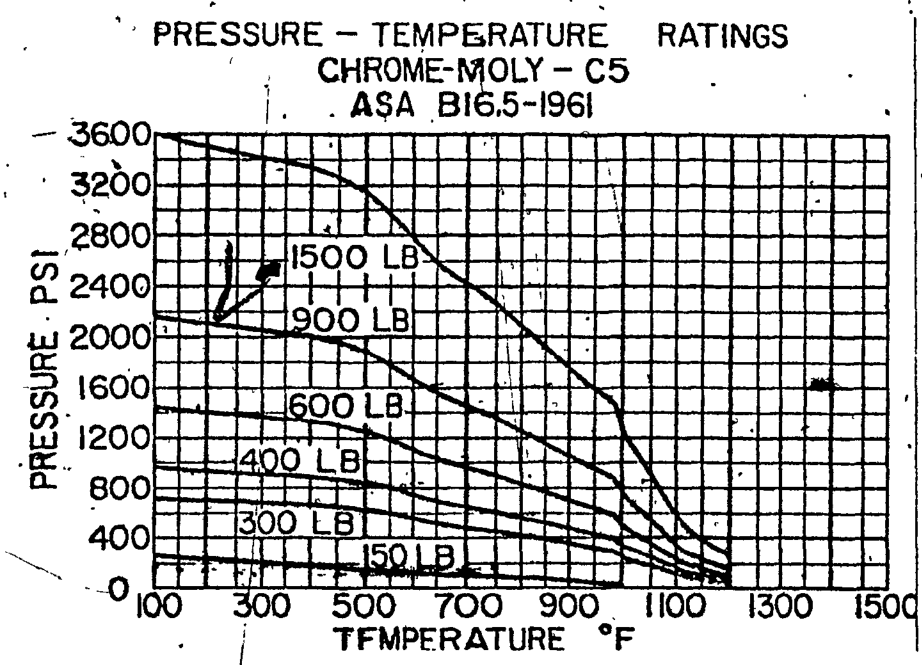
Class	Body Materials	Pressure Standards (PSIG)	
1	C5	1500	2500
2	C5	1500	2500
3	C5	1500	2500
4	Iron; WCB; WC6; C5	250;300;600;900; 1500	2500
5	C5	1500	2500
6	C5	1500	2500
7	C5	1500	2500
8	C5	1500	2500

The body material and pressure standard is selected using the charts or tables which follow.

A.S.A. Charts.



DATA EXTRACTED FROM ASA B16.1-1960, B16.2-1960 & B16.4-1949



QUALITY OF STEAM

Fig. A.2.

Table A.6.I ASA Rating For Carbon Steel and Chrome Moly

Extracted from ANSI B16.5 - 1968. Steel Pipe Flanges and Flanged Fittings

Service Temp. °F	Carbon Steel - Grade WCB					
	Pressure Standard - psig					
	150	300 Δ	600 Δ	900	1500	2500
-20 to 100δ	275	720	1440	2160	3600	6000
150	255	710	1420	2130	3550	5915
200	240	700	1400	2100	3500	5830
250	225	690	1380	2070	3450	5750
300	210	680	1365	2050	3415	5690
350	195	675	1350	2025	3375	5625
400	180	665	1330	2000	3330	5550
450	165	650	1305	1955	3255	5430
500	150	625	1250	1875	3125	5210
550	140	590	1180	1775	2955	4925
600	130	555	1110	1660	2770	4620
650	120	515	1030	1550	2580	4300
700	110	470	940	1410	2350	3920
750	100	425	850	1275	2125	3550
800	92	365	730	1100	1830	3050
ANSI Code B31.1.0 for power piping forbids the use of carbon steel castings for temperatures in excess of 800F.						
Test Pressure psig	425	1100	2175	3250	5400	9000

1 - 1-1/2% Chrome-Moly - Grade WC6						Service Temp. °F
Pressure Standard - psig						
150	300 Δ	600 Δ	900	1500	2500	
275	720	1440	2160	3600	6000	-20 to 100δ
255	710	1420	2130	3550	5915	150
240	700	1400	2100	3500	5830	200
225	690	1380	2070	3450	5750	250
210	680	1365	2050	3415	5690	300
195	675	1350	2025	3375	5625	350
180	665	1330	2000	3330	5550	400
165	650	1305	1955	3255	5430	450
150	625	1250	1875	3125	5210	500
140	590	1180	1775	2955	4925	550
130	555	1110	1660	2770	4620	600
120	515	1030	1550	2580	4300	650
110	485	965	1450	2415	4025	700
100	450	900	1350	2250	3745	750
92	415	835	1250	2080	3470	800
82	385	765	1150	1915	3190	850
75	365	735	1100	1830	3055	875
70	350	700	1050	1750	2915	900
60	335	665	1000	1665	2775	925
55	315	635	950	1585	2640	950
50	300	600	900	1500	2500	975
40	265	535	800	1335	2230	1000
-	230	455	685	1140	1900	1025
-	190	375	565	945	1570	1050
-	165	325	490	815	1355	1075
-	135	275	410	685	1145	1100
ANSI Code B31.1.0 for power piping forbids the use of WC6 castings for temperatures in excess of 1100F.						
425	1100	2175	3250	5400	9000	Test Pressure psig

Table A.6.2 ASA Rating For Carbon Steel

Extracted from ANSI B16.5 – Steel Pipe Flanges and Flanged Fittings

Service Temp. °F	4-6% Chrome-Moly - Grade C5						TYPE 304 Stainless Steel						Service Temp. °F
	Pressure Standard - psig						Pressure Standard - psig						
	150	300 Δ	600 Δ	900	1500	2500	150	300 Δ	600 Δ	900	1500	2500	
-20 to 100	275	720	1440	2160	3600	6000	275	615	1235	1850	3085	5145	-20 to 100
150	255	710	1420	2130	3550	5915	255	585	1165	1750	2915	4855	150
200	240	700	1400	2100	3500	5830	240	550	1095	1645	2740	4565	200
250	225	690	1380	2070	3450	5750	225	520	1040	1565	2605	4340	250
300	210	680	1365	2050	3415	5690	210	495	985	1480	2470	4115	300
350	195	675	1350	2025	3375	5625	195	470	945	1415	2360	3930	350
400	180	665	1330	2000	3300	5550	180	450	900	1350	2245	3745	400
450	165	650	1305	1955	3255	5430	165	430	860	1290	2150	3585	450
500	150	625	1250	1875	3125	5210	150	410	825	1235	2055	3430	500
550	140	590	1180	1775	2955	4925	140	395	795	1190	1985	3305	550
600	130	555	1110	1660	2770	4620	130	380	765	1145	1910	3180	600
650	120	515	1030	1550	2580	4300	120	370	735	1105	1845	3070	650
700	110	485	965	1450	2415	4025	110	355	710	1065	1775	2960	700
750	100	450	900	1350	2250	3745	100	340	685	1025	1710	2850	750
800	92	415	835	1250	2080	3470	92	330	660	985	1645	2745	800
850	82	385	765	1150	1915	3190	82	320	640	960	1595	2660	850
875	75	365	735	1100	1830	3055	75	315	630	945	1570	2620	875
900	70	350	700	1050	1750	2915	70	310	620	930	1545	2580	900
925	60	335	665	1000	1665	2775	60	305	615	920	1535	2560	925
950	55	315	635	950	1585	2640	55	305	610	915	1525	2540	950
975	50	300	600	900	1500	2500	50	300	605	905	1510	2520	975
1000	40	250	500	750	1250	2085	40	300	600	900	1500	2500	1000
1025	-	215	430	645	1070	1785	-	295	595	890	1485	2470	1025
1050	-	180	355	535	890	1485	-	290	585	875	1455	2430	1050
1075	-	145	290	435	730	1215	-	275	550	825	1370	2285	1075
1100	-	115	225	340	565	945	-	255	515	770	1285	2145	1100
1150	-	75	150	225	375	630	-	195	395	590	985	1645	1150
1200	-	50	105	155	255	430	-	155	310	465	770	1285	1200
Test Pressure psig	425	1100	2175	3250	5400	9000	425	1100	1875	2775	4650	7725	Test Pressure psig

Table A.6.3 ASA Rating For Stainless Steel

Extracted from ANSI B16.5 - Steel Pipe Flanges anf Flan

Service Temp. °F	Types 316, 321 & 347 Stainless Steel — Pressure Rating - psig: 150	300 Δ	600 Δ	900	1500	2500
-20 to 100	275	720	1440	2160	3600	6000
150	255	710	1420	2130	3550	5915
200	240	700	1400	2100	3500	5830
250	225	690	1380	2070	3450	5750
300	210	680	1365	2050	3415	5690
350	195	675	1350	2025	3375	5625
400	180	665	1330	2000	3330	5550
450	165	650	1305	1955	3255	5430
500	150	625	1250	1875	3125	5210
550	140	590	1180	1775	2955	4925
600	130	555	1110	1660	2770	4620
650	120	515	1030	1550	2580	4300
700	110	495	985	1480	2465	4110
750	100	470	940	1410	2355	3920
800	92	450	895	1345	2240	3730
850	82	425	850	1275	2125	3540
875	75	415	825	1240	2070	3445
900	70	400	805	1205	2010	3350
925	60	390	780	1175	1955	3260
950	55	380	760	1140	1900	3165
975	50	370	735	1105	1840	3070
1000	40	355	715	1070	1785	2975
1025	-	345	690	1035	1725	2880
1050	-	335	670	1000	1670	2785
1075	-	325	645	970	1615	2690
1100	-	310	625	935	1555	2595
1125	-	300	600	900	1500	2500
1150	-	290 †	585 †	875 †	1455 †	2430 †
1200	-	235 †	465 †	700 †	1165 †	1945 †
Test Pressure psig	425	1100	2175	3250	5400	9000

Table A.6.4 ASA Rating For Cast Iron

Data extracted from ANSI B16.1 and B16.4.

125 lb - 250 lb — Screwed or Flanged Ends

Temperature °F	125 lb ASTM A126 CLASS A Sizes 1-12	125 lb ASTM A126 CLASS B Sizes 14-24	250 lb ASTM A126 CLASS A Sizes 1-12	250 lb ASTM A126 CLASS B Sizes 14-24(c)
-20 to 150	175	150	400	300
200	165	135	370	280
225	155	130	355	270
250	150	125	340	260
275	145	120	325	250
300	140	110	310	240
325	130	105	295	230
350(a)	125	100	280	220
375			265	210
400(b)			250	200

A.4. SIZING CALCULATIONS.

The sizing calculations provide a mathematical means of determining the proper valve size to meet the service conditions.

Depending on the type of fluid, various calculations must be performed as follows:

Table A.7 Calculations Required.

Fluid	Calculations
Oil	1) Viscosity Correction Factor 2) Port Area
Gas; Stm; SS; DSS; WSS	1) Critical Pressure Drop 2) Port Area
Liquid	1) Critical Pressure Ratio 2) Allowable Pressure Drop 3) Viscosity Correction Factor 4) Port Area.

The details of these calculations are:

A.4.1. Critical Pressure Drop.

The critical pressure drop through a valve is defined as that value above which no increase in flow will result for a further decrease in outlet pressure.

The following formulae apply:

For air or gas - $\Delta P = .47 \times P$ (abs)

For superheated steam- $\Delta P = .45 \times P$ (abs)

For saturated steam - $\Delta P = .42 \times P$ (abs)

Compare the value of P obtained from the appropriate formula with the actual drop specified between inlet and outlet. Use the smaller value in calculating port area.

A.4.2. Critical Pressure Ratio.

The critical pressure ratio "R" is determined from Fig. A.4 as a function of static inlet pressure.

A.4.3. Allowable Pressure Drop.

The allowable pressure drop is a result of the following calculation

$$P \text{ (allow)} = Km\,(P_1 - r_c P_v).$$

For complete details concerning this equation, refer to the "Valve Sizing for Cavitating and Flashing Liquids" which follows.

A.4.4. Valve Sizing for Cavitating and Flashing Liquids.

Introduction

The procedure used to size control valves for liquid service should consider the possibility of cavitation and flashing since they can limit the capacity and produce physical damage to the valve. This recommendation introduces a critical pressure ratio factor, r_c, that not only broadens the scope of our valve sizing techniques but also increases the sizing accuracy. When used in Equation 1, r_c will help to determine more accurately the maximum allowable pressure drop for sizing purposes. In order to understand the problems more thoroughly, brief outlines of the cavitation and flashing processes are presented.

Cavitation

In a control valve, the fluid stream is accelerated as it flows through the restricted area of the orifice, reaching maximum velocity at the vena contracta*. Simultaneously, as the velocity increases, an interchange of energy between the velocity and pressure heads forces a reduction in the pressure. If the velocity increases sufficiently, the pressure at the vena contracta will be reduced to the vapor pressure of the liquid. At this point, voids or cavities, the first stage in cavitation, appear in the fluid stream. Downstream from the vena contracta, the fluid stream undergoes a deceleration process resulting in a reversal of the energy interchange and raising the pressure above the liquid vapor pressure. The vapor cavities cannot exist at the increased pressure and are forced to collapse or implode. These implosions, the final stage in the cavitation process, produce noise, vibration and physical damage. In order to avoid cavitation completely, the pressure at the vena contracta must remain above the vapor pressure of the liquid.

Flashing

The first stages of cavitation and flashing are identical, i.e., vapor forms as the vena contracta pressure is reduced to the vapor pressure of the liquid. In the second stage of the flashing process, a portion of the vapor formed at the vena contracta remains in the vapor state because the downstream pressure is equal to or less than the vapor pressure of the liquid.

*In flow through an orifice, the fluid streamlines converge before and slightly after the orifice. The section of minimum diameter of the fluid stream after the orifice is known as the vena contracta.

Sizing Information

After the first vapor cavities are formed, the increase in flow rate will no longer be proportional to an increase in the square root of the body differential pressure. When sufficient vapor has been formed, the flow will become completely choked so that there will be no increase in flow as ΔP is increased. The following equation should be used to determine the maximum allowable pressure drop that is *effective in producing flow*. It should be noted, however, that this limitation on the sizing pressure drop, $\Delta P_{(allow)}$, does not imply that this is the maximum drop that may be handled by the valve.

$$\Delta P_{(allow)} = K_m(P_1 - r_c P_v) \qquad \text{(Equation 1)}$$

After $\Delta P_{(allow)}$ has been calculated, it is used in the standard liquid sizing equation, $Q = C_v\sqrt{\Delta P/G}$ to determine either Q or C_v. If the actual ΔP is less than $\Delta P_{(allow)}$, then the actual ΔP should be used in the liquid sizing equation.

Equation 1 should also be used to calculate the body pressure drop at which significant cavitation can occur. It is recognized that minor cavitation will occur at a pressure drop slightly less than that predicted by Equation 1. However, any cavitation under that pressure drop condition should produce negligible damage.

It is recommended that the fluid name, temperature and vapor pressure be included with all orders so that the valve sizing can be checked.

NOMENCLATURE

C_v	=	liquid sizing coefficient
Q	=	flow rate, gpm
ΔP	=	body differential pressure, psi
$\Delta P_{(allow)}$	=	maximum allowable differential pressure for sizing purposes, psi
P_1	=	body inlet pressure, psia
P_v	=	vapor pressure of liquid at body inlet temperature, psia
K_m	=	valve recovery coefficient—see Section I of this catalog
r_c	=	critical pressure ratio—see Figures 1 and 2
G	=	specific gravity (water at 60°F = 1.0)

—Continued on Next Page—

Critical Pressure Ratios For Water

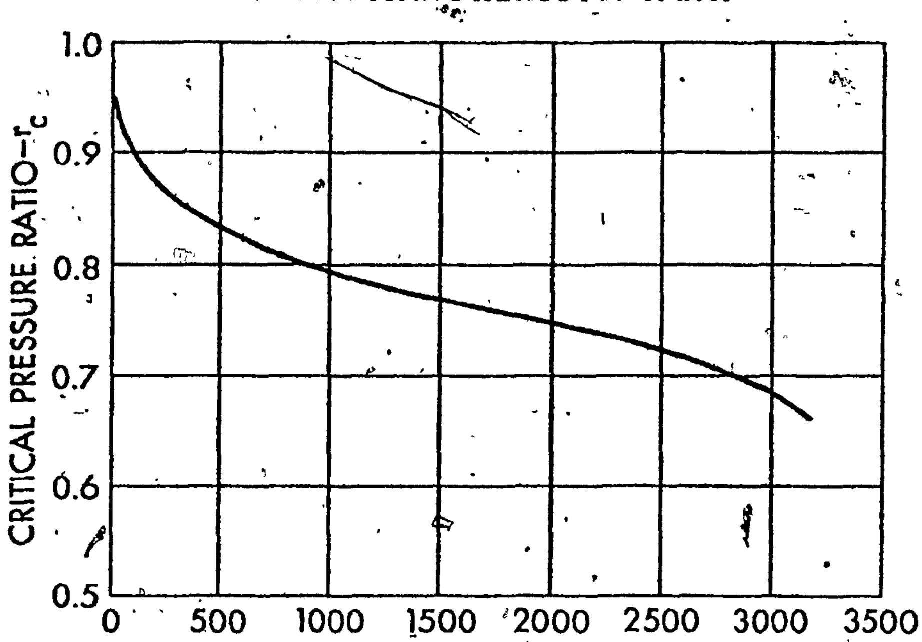


FIG A-3

Figure 1. Use this curve for water. Enter on the abscissa at the water vapor pressure at the valve inlet. Proceed vertically to intersect the curve. Move horizontally to the left to read the critical pressure ratio, r_c, on the ordinate.

Critical Pressure Ratios For Liquids Other Than Water

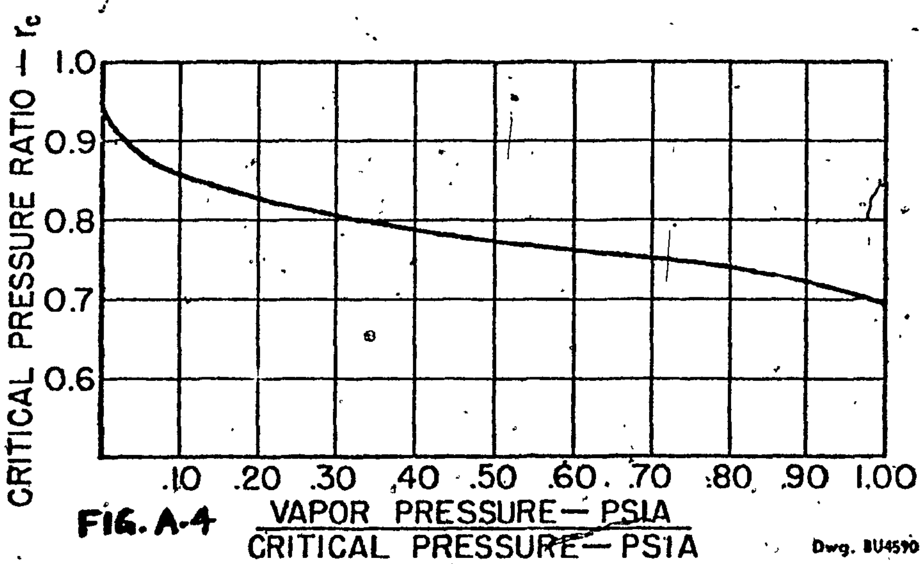


FIG. A-4

Dwg. 8U4590

Figure 2. Use this curve for liquids other than water. Determine the vapor pressure/critical pressure ratio by dividing the liquid vapor pressure at the valve inlet by the critical pressure of the liquid. Enter on the abscissa at the ratio just calculated and proceed vertically to intersect the curve. Move horizontally to the left and read the critical pressure ratio, r_c, on the ordinate.

Critical Pressure of Various Fluids, Psia*

Ammonia	1636
Argon	705.6
Butane	550.4
Carbon Dioxide	1071.6
Carbon Monoxide	507.5
Chlorine	1118.7
Dowtherm A	465
Ethane	708
Ethylene	735
Fluorine	808.5
Helium	33.2
Hydrogen	188.2
Hydrogen Chloride	1198
Isobutane	529.2
Isobutylene	580
Methane	673.3
Nitrogen	492.4
Nitrous Oxide	1047.6
Oxygen	736.5
Phosgene	823.2
Propane	617.4
Propylene	670.3
Refrigerant 11	635
Refrigerant 12	596.9
Refrigerant 22	716
Water	3206.2

*For values not listed, consult an appropriate reference book.

A.4.5. Viscosity Correction Factor.

The velocity correction factor is a result of the following table.

Fig. A.8. Viscosity Correction Factors.

ssu	μ	ssu	μ
To 50	1.0	800	1.45
70	1.07	1000	1.50
100	1.13	2000	1.58
200	1.25	3000	1.60
400	1.35		

A.4.6. Port Area.

The formula for calculating port area for various fluids are as follows:

LIQUIDS: $A = F(W, V, F, \gamma, \Delta P, C)$

STEAM: $A = F(W, S, F, Y, \Delta P, P, C)$

AIR or GAS: $A = F(Q, G, T, \Delta P, P, F, Y, C)$

A = Required port area, sq.in.
F = Valve coefficient
G = Specific Gravity (=1.0 for air)
ΔP = Pressure drop through valve at max.flow, psi.
P = Inlet absolute pressure, psia
Q = Max. Capacity, standard cubic feet per hour (scfh)
S = Steam Superheat, degrees F
T = Flowing temperature, degrees F
V = Steam specific volume, cu.ft. per lb.
W = Maximum capacity, lb.per hr.
Y = Expansion factor
γ = Specific Weight, lb.per cu.ft.
μ = Viscosity corr. factor
C = A Constant

A.4.7. Size Selection.

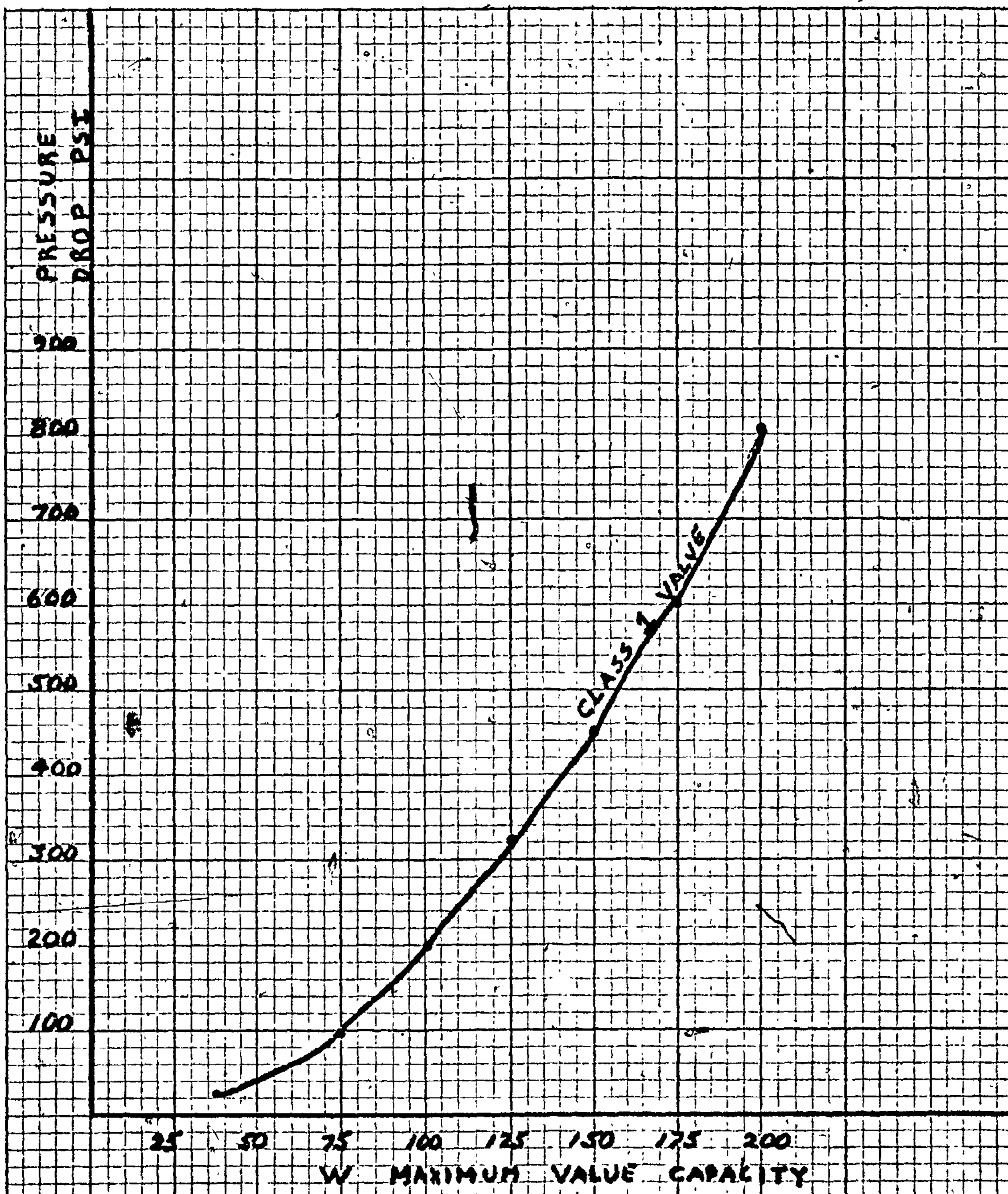
The actual size selection based on the foregoing calculations varies for each valve class. For the purposes of this description, only Class 1 Valves will be considered.

Using the curve shown in Fig. A.5., the maximum process flow is compared against the maximum valve capacity. If the process flow is within allowable limits, the body sizes are selected using the following table:

Table A.9. Body Sizes.			
Size	Capacity lb./hr.	Size	Capacity lb./hr.
1"	45,000	2"	200,000 (△△)
1 1/4	90,000	2 1/2	200,000
1 1/2	120,000	3"	200,000
2"	150,000 (△)		

Maximum Valve Capacity.

Fig. A.5.



Maximun Valve Capacity

Fig. A-5

A.4.8. Velocity.

To determine the actual velocity of the fluid flowing to or from a given valve, or to calculate the minimum body size (inlet or outlet area) required for the maximum velocity permitted, use the following formulae:

GASES (Air)	LIQUIDS	STEAM
$V = F(C, W, A, Y)$	$V_1 = F(C, W, A, d)$	$V = F(C, W, V, A)$
$A_{min} = F(C, W, Y, V)$	$A_{min} = F(C, W, d, V)$	$A_{min} = F(C, W, V, v)$

where:

A = Actual valve inlet or outlet area (pipe area), sq.in.

Amin = Minimum valve inlet or outlet area, sq.in. required for maximum velocity permitted

d = Specific weight of liquid, lb per cubic food

V = Actual velocity at valve inlet or outlet, feet per minute (air, gas or steam)

V_1 = Actual velocity at valve inlet or outlet, feet per second (liquids)

V_{max} = Maximum inlet or outlet velocity permitted, feet per minute (air, gas or steam)

V_{1max} = Maximum inlet or outlet velocity permitted, feet per second (liquids)

v = Specific volume of steam at valve inlet or outlet, cubic feet per lb.

W = Valve capacity, pounds per hour

Y = Specific weight of gas, lb per cubic food
or
Specific weight of air at flowing temperature x g x $\frac{P(abs)}{P(atm)}$

where:

g = Specific gravity of gas (air = 1.0)

P(abs) = Absolute static pressure at valve inlet or outlet, psia

P(atm) = Atmospheric pressure, psia.

A.5. ACTUATOR SELECTION.

The actuator selection procedure for Class 1 Valves is a result of the following table:

Table A.10 Actuator Type

Valve Position Inlet Pressure	No 3615	No 3815	NC 3615	NC 5515
Actuator Type	A	B	A	B

A.6. SYSTEM OUTPUT.

The system output consists of the Proposal Price Make-up Sheet shown in Fig. A.12 and the Valve Specification Sheet shown in Fig. A.13.

VALVE SPECIFICATION.

Item Number: Quantity:

Service :

Body Size:
Class :
Fluid :
Capacity :
Inlet Pressure:
Pressure:
Temperature:
Specific Gravity:

Body Pressure Std
Body Material

Actuator

Accessories

Shipping Wgt.
Air Consumption
Remarks.

Fig. A-12

VALUE PRICE MAKE-UP

Item Number: Quantity:

Description		Price
Body	Pressure Std:	______
	Material :	______
Actuator	Size :	______
Accessories		______
		______
		______
		______
Shipping Wgt.	:	______

Total Price ______

X Quantity ______

Fig. A-13

APPENDIX B

PROPOSED SYSTEM REQUIREMENTS.

B.1. SYSTEM INPUTS.

Symbol	Description	Function	Units
SERV	Valve Service	T101	1. Atomizing Steam Shut-Off 2. Boiler Auxiliaries 3. Desuperheater Water Spray. 4. Feedwater Flow. 5. Heater Level Control. 6. Oil Shut-Off. 7. Oil Burner Control. 8. Pump Recirculation Shut-Off. 9. Superheater Spray Water Control. 10. Reheat Spray Water Control. 11. Superheater Spray Water Shut-Off. 12. Reheat Spray Water Shut-Off. 13. Steam Pressure Reducing.
T	Fluid Temperature	T129	Degrees F
PA	Static Inlet Pressure	T129	PS1A
PD	Pressure Drop	T600	PS1
VIS	Viscosity	T604	SSU
W	Max.Valve Capacity(LIQ)	T605	Lbs./hr.
SPC	Specific Gravity (LIQ)	T605	
Q	Max.Valve Capacity(GAS)	T605	SchF
G	Specific Gravity (GAS)	T605	
VLUPS	Valve Position	T606	NO: normally open normally closed.

B.2 INTERNAL VARIABLES.

Symbol	Description	Defining Function	Units
SELROU	System Flag	T5	
Class	Valve Class or Type	T101	Class 1 2 3 4
Fluid	Process Fluid	T10T	1: Steam 2: Liquid 3: Oil 4: Dry Saturated Steam 5: Wet Saturated Steam 6: Saturated Steam
F	Valve Sizing Coefficient	T101	
SX	Vapor Pressure Coefficient	T120 to T128	Degrees F
PV	Vapor Pressure	T120 to T128	PS1A
PG	Static Inlet Pressure	T310	PS1G
PRSTD	Valve Body Pressure Standard	T320	250 lbs. 300 lbs. 600 lbs. 900 lbs. 1500 lbs. 2500 lbs.
BDYMAT	Valve Body Material	T320	1: C5 2: Iron 3: WCB 4: WC6
PDC	Calculated Pressure Drop	T601,T603	PS1A
RC	Sizing Coefficient	T602	
KM	Sizing Coefficient	T602	
U	Sizing Coefficient	T604	
A	Valve Port Area	T605	
Y	Viscosity Correction Factor	T605	

INTERNAL VARIABLES (cont'd.)

Symbol	Description	Defining Function	Units
ID	Valve Inlet Diameter	T607A	inches
OD	Valve Outlet Diameter	T607A	inches
AI	Valve Inlet Area	T607A	square inches
AO	Valve Outlet Area	T607A	square inches
PDP	Maximum Capacity Coefficient	T608	
W1	Sizing Coefficients	T609	
DP1	Sizing Coefficients	T609	
W2	Sizing Coefficients	T609	
DP2	Sizing Coefficients	T609	
VO	Outlet Linear Velocity	T609	
VI	Inlet Linear Velocity	T609	60
ACT	Actuator Size	T1001	70

B.3 SYSTEM OUTPUTS.

VALVE SPECIFICATION.

Item Number: Quantity:

Service :

Body Size:
Class :
Fluid :
Capacity :
Inlet Pressure:
Pressure:
Temperature:
Specific Gravity:

Body Pressure Std
Body Material

Actuator

Accessories

Shipping Wgt.
Air Consumption
Remarks.

VALUE PRICE MAKE-UP

Item Number: Quantity:

Description		Price
Body	Pressure Std:	______
	Material :	______
Actuator	Size :	______
Accessories		______
		______
		______
		______
Shipping Wgt.	:	______

Total Price ______

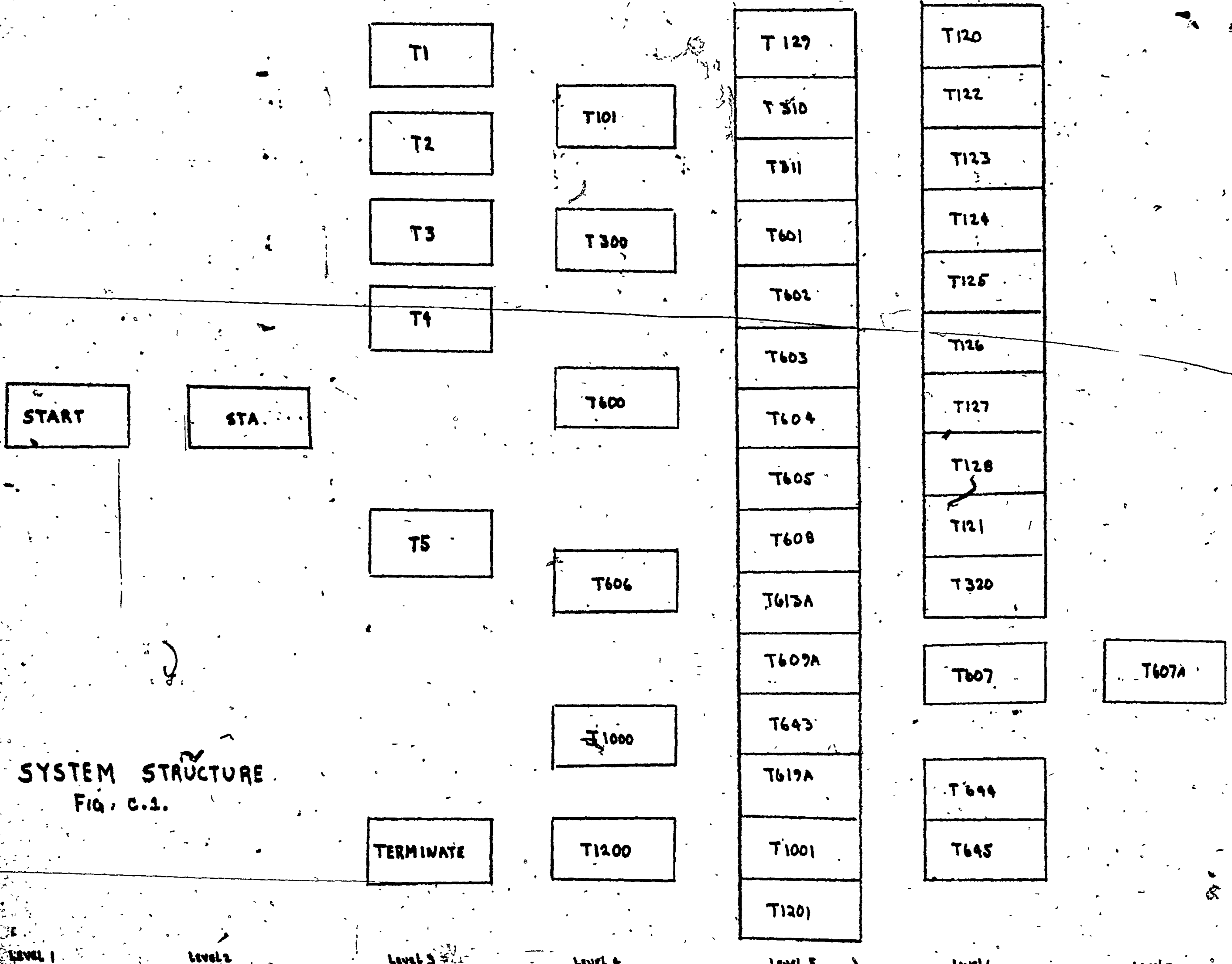
X Quantity ______

APPENDIX C.

SYSTEM DESIGN.

C.1. SYSTEM STRUCTURE.

The CAPP system is designed using a structured programming approach. The system structure is shown in Fig. C.1.



SYSTEM STRUCTURE
Fig. c.1.

C-2 FUNCTION FORMAT.

TABLE NUMBER TABLE NAME

SYSTEM CAPP DECISION TABLE Analyst

Page of Date

TABLE FUNCTION:

CONDITIONS	RULES	RULES
ACTIONS		

MISCELLANEOUS COMMENTS:

C.3. SYSTEM FUNCTIONS.

START INTRODUCTION

SYSTEM ______ DECISION TABLE Analyst ______
Page ______ of ______ Date ______

FUNCTION: TO PROVIDE SYSTEM INTRODUCTION
THIS IS A NO CONDITION DECISION TABLE.

```
[1]   →2
[2]   '
                    COMPUTER ASSISTED PROPOSAL PREPARATION'
[3]   '
[4]   '                          FOR'
[5]   '                   CLASS 1, 2, 3 VALUES'
[6]   '                 * VERSION 1 * MAY 1973 *'
[7]   '

                             MODE SELECTION'
[8]   '                          **************'
[9]   '     FOR SYSTEM DESCRIPTION TYPE            :T1'
[10]  '     FOR OPERATION DESCRIPTION TYPE         :T2'
[11]  '     FOR LIST OF INPUT VARIABLES TYPE       :T3'
[12]  '     FOR SAMPLE RUN TYPE                    :T4'
[13]  '     FOR EXECUTION TYPE                     :T5'
[14]  '     FOR TERMINATION TYPE                   :TERMINATE'
[15]  STA
    ∇
```

STA MODE SELECTION TABLE

DECISION TABLE

SYSTEM

Page of

Analyst

Date

FUNCTION: BRANCH DEPENDING ON MODE SELECTED

IF MODE =	T1	T2	T3	T4	T5	TERMINATE
DO TABLE	T1	T2	T3	T4	T5	TERMINATE
ITERATE	X	X	X	X	X	

T1 SYSTEM DESCRIPTION

SYSTEM________ DECISION TABLE Analyst________

Page______ of______ Date________

FUNCTION: A NO CONDITION TABLE WHICH GIVES A SYSTEM DESCRIPTION MESSAGE.

```
∇T1[⎕]∇
    ∇ T1
[1]    '              SYSTEM DESCRIPTION'
[2]    '              ******************'
[3]    '
[4]    '
[5]    'THE PURPOSE OF A COMPUTER ASSISTED PROPOSAL PREPARATION'
[6]    'SYSTEM , CAPP , IS TO PROVIDE AN EFFICIENT MEANS OF'
[7]    'PREPARING CONTROL SYSTEM VALUE PROPOSALS. THE USER'
[8]    'MUST ANALYSE AND INTERPRET THE CUSTOMER SPECIFICATIONS'
[9]    'AND DEFINE THE SERVICE CONDITIONS AFFECTING THE EQUIPMENT'
[10]   'SELECTION. USING THESE CONDITIONS AS INPUTS, CAPP WILL'
[11]   'THEN PERFORM EQUIPMENT SELECTION AND PROVIDE A PRINTOUT'
[12]   'OF EQUIPMENT DOCUMENTATION AND PRICING.'
[13]   STA
    ∇
```

T2 SYSTEM OPERATION

SYSTEM ___ DECISION TABLE Analyst ___

Page ___ of ___ Date ___

FUNCTION: A NO CONDITION TABLE WHICH GIVES A SYSTEM OPERATION MESSAGE.

```
∇T2[⎕]∇
    ∇ T2
[1]    '               SYSTEM OPERATION'
[2]    '               ****************'
[3]    ''
[4]    ''
[5]    'CAPP IS DESIGNED WITH USER CONVIENCE IN MIND. USING THE'
[6]    'SYSTEM SIMPLY CONSISTS OF PROVIDING ANSWERS TO THE'
[7]    'QUESTIONS ASKED. THE SYSTEM CHECKS THE VALUES ENTERED TO'
[8]    'VERIFY THAT THEY ARE WITHIN ALLOWABLE LIMITS. A COMPLETE'
[9]    'LIST OF SYSTEM VARIABLES IS GIVEN IN MODE T3. AND A SAMPLE'
[10]   'SESSION IS GIVEN IN MODE T4. REFER TO THE SYSTEM USERS'
[11]   'MANUAL FOR A COMPLETE DESCRIPTION OF SYSTEM OPERATION.'
[12]   STA
    ∇
```

T3 LIST OF SYSTEM VARIABLES

DECISION TABLE

No. ______ of ______ Analyst ______ Date ______

FUNCTION: A NO CONDITION TABLE WHICH GIVES A LIST OF SYSTEM INPUT VARIABLES.

```
∇T3[⎕]∇
    ∇ T3
[1]    '            SYSTEM VARIABLES'
[2]    '            ****************'
[3]    ' '
[4]    ' '
[5]    '            INPUT VARIABLES'
[6]    '
[7]    ' '
[8]    'SYMBOL      DESCRIPTION       FUNCTION         UNITS'
[9]    ' '
[10]   'SERV   VALVE SERVICE          T101  1:ATOMIZING STEAM SHUT OFF'
[11]   '                                    2:BOILER AUXILLIARIES'
[12]   '                                    3:DESUPERHEATER/WATER SPRAY'
[13]   '                                    4:FEEDWATER FLOW'
[14]   '                                    5:HEATER LEVEL CONTROL'
[15]   '                                    6:OIL SHUT OFF'
[16]   '                                    7:OIL BURNER CONTROL'
[17]   '                                    8:PUMP RECIRC SHUT OFF'
[18]   '                                    9:SUPERHEATER SPRAY CONTROL'
[19]   '                                   10:REHEAT SPRAY CONTROL'
[20]   '                                   11:SUPERHEATER SPRAY SHUT OFF'
[21]   '                                   12:REHEAT SPRAY SHUT OFF'
[22]   '                                   13:STEAM PRESSURE REDUCING'
[23]   'T      FLUID TEMPERATURE        T101        DEGREES F'
[24]   'PA     STATIC INLET PRESSURE    T129        PSIA'
[25]   'PD     PRESSURE DROP            T600        PSI'
[26]   'VIS    VISCOSITY                T604        SSU'
[27]   'W      MAX VALVE CAPACITY(LIQ)  T605        LBS/HR'
[28]   'SPC    SPECIFIC GRAVITY(LIQ)    T605'
[29]   'Q      MAX VALVE CAPACITY(GAS)  T605        SCHF'
[30]   'G      SPECIFIC GRAVITY(GAS)    T605'
[31]   'VLVPOS VALVE POSITION           T606  NO:NORMALLY OPEN'
[32]   '                                      NC:NORMALLY CLOSED'
[33]   STA
```

T4 SAMPLE SESSION

SYSTEM ______ DECISION TABLE Analyst ______

Page ______ of ______ Date ______

FUNCTION: A NO CONDITION TABLE WHICH GIVES A SAMPLE SESSION MESSAGE.

```
∇T4[⎕]∇
    ∇ T4
[1]   '             SAMPLE SESSION'
[2]   '             **************'
[3]   ' '
[4]   'FOR A COMPLETE EXAMPLE OF A SYSTEM SESSION REFER TO'
[5]   'THE CAPP USERS MANUAL'
[6]   STA
    ∇
```

T5 SYSTEM EXECUTION

SYSTEM ________ **DECISION TABLE** Analyst ________

Page ____ of ____ Date ________

FUNCTION: A NO CONDITION TABLE WHICH CONTROLS THE FLOW OF SYSTEM EXECUTION

DO TABLE 101	X
DO TABLE 300	X
DO TABLE 600	X
DO TABLE 606	X
DO TABLE 1000	X
DO TABLE 1200	X
RETURN (STA)	X

TERMINATE SYSTEM TERMINATION

SYSTEM ______ DECISION TABLE Analyst ______

Page ______ of ______ Date ______

FUNCTION: TERMINATES THE SESSION AND INITIALIZES THE VALUES OF ALL VARIABLES. THIS IS A NO CONDITION TABLE

TERMINATE MESSAGE	X
INITIALIZE ALL VARIABLES	X
TERMINATE SESSION	X

T101 SERVICE MANAGEMENT

SYSTEM ________ DECISION TABLE Analyst ________

Page ____ of ____ Date ________

FUNCTION: SELECT CLASS AND FLUID AS A RESULT OF THE SERVICE ENTERED ALSO SELECT F AND BRANCH TO T129

	Rule 1	Rule 2	Rule 3	Rule 4	Rule 5	Rule 6	Rule 7	Rule 8	Rule 9
IF SERV =	01	02	03	03	04	05	06	07	08
IF SELROU =	01	01	01	02	01	01	01	01	01
SET CLASS =	1	2	2	2	4	4	1	2	1
SET FLUID =	STM	STM	LIQ	LIQ	LIQ	LIQ	OIL	OIL	LIQ
DO T129	X	X	X	X	X	X			X
SET F =	.65	.65	.65	.65	.50	.50	.65	.65	.65
RETURN (T5)	X	X	X	X	X	X	X	X	X

COMMENTS:

(a) CODES

01 → ATOMIZING STEAM SHUTOFF
02 → BOILER AUXILLIARIES
03 → DESUPERHEATER WATER SPRAY
04 → FEEDWATER FLOW
05 → HEATER LEVEL CONTROL
06 → OIL SHUTOFF
07 → OIL BURNER CONTROL
08 → PUMP RECIRC SHUTOFF
09 → SUPER HEAT SPRAY WATER CONTROL
10 → REHEAT SPRAY WATER CONTROL
11 → SUPER HEAT SPRAY WATER SHUTOFF
12 → REHEAT SPRAY WATER SHUTOFF
13 → STEAM PRESSURE REDUCING

T 101 (CONTINUED) SERVICE MANAGEMENT CONTINUED.

SYSTEM ______ DECISION TABLE Analyst ______
Page ____ of ____ Date ______

IF SERV =	02	02	10	10	11	12	13	13	+
IF SEL ROU =	01	02	01	02	01	01	01	22	−
SET CLASS =	2	2	2	2	1	1	2	2	
SET FLUID =	L10	L10	L10	L10	L10	L10	ST7	ST7	
DO T129	X	X	X	X	X	X	X	X	
SET F	.65	.65	.65	.65	.65	.65	.65	.50	
RETURN	X	X	X	X	X	X	X	X	
ERROR									X
									X

(B) Variables

SERV: input
SEL ROU: action from Table 607 + 608
CLASS: defined + used in tables 606, 1000
FLUID: " " " " " TO 1202, 130, 600, 605, 613, 800
f : " " " " " TO 605

T 120 Quality of Steam

SYSTEM ______ DECISION TABLE Analyst ______
Page ______ of ______ Date ______

FUNCTION: TEST FOR QUALITY OF STEAM.

	1	2	3	4	5
IF $T \le (187+1.68R)+5$	Y	N	Y	Y	N
IF $T > (187+1.68R)-5$	Y	Y	N	—	Y
IF FLUID =	STM	STM	STM	LIQ	LIQ
SET $P_v = (T-187)/1.68$				X	
SET $S = 0.0$	X		X		
SET $S = T-(187+1.68R)$		X			
SET FLUID = DSS	X				
SET FLUID = SS		X			
SET FLUID = WSS			X		
RETURN (127)	X	X	X	X	
ERROR STATEMENT					X

Variables:

T : input

FLUID: from TO102

P_v : set & use 602, 603

S : " " " TO 605

FLUID : set: DSS, SS, WSS & use in Table 600, 605

T121 QUALITY OF STEAM

SYSTEM________ Page____ of____

DECISION TABLE

Analyst________ Date________

$T \le (250.4 + 0.74 P_a) + 5.$	Y	N	Y	Y	N
$T > (250.4 + 0.74 P_a) - 5.$	Y	Y	N	–	Y
FLUID IS	STM	STM	STM	LIQ	LIQ
$P_v = (T - 250.4)/0.74$				X	
DO					
ERROR STATEMENT					X
$S = 0.0$	X		X		
$S = T - (250.4 + 0.74 P_a)$		X			
FLUID IS DSS	X				
FLUID IS SS		X			
FLUID IS WSS			X		
RETURN T127	X	X	X	X	

T122 QUALITY OF STEAM

SYSTEM ________ Page ____ of ____

DECISION TABLE

Analyst ________ Date ________

T = (301.54 + 0.36P) + 5.	Y	N	Y	Y	N
T > (301.54 + 0.36P) − 5.	Y	Y	N	−	Y
FLUID IS	STM	STM	STM	LIQ	LIQ
P = (T − 301.54)/0.36				X	
DO					
ERROR STATEMENT					X
S = 0.0	X		X		
S = T − (301.54 + 0.36P)		X			
FLUID IS DSS	X				
FLUID IS SS		X			
FLUID IS WSS			X		
RETURN (T129)	X	X	X	X	

T123 QUALITY OF STEAM

SYSTEM ____ Page ____ of ____

DECISION TABLE

Analyst ____ Date ____

$T \le (329.0+0.29P_v)+5.$	Y	N	Y	Y	N
$T > (329.0+0.29P_v)-5.$	Y	Y	N	–	Y
FLUID IS	STM	STM	STM	LIQ	LIQ
$P_v=(T-329.0)/0.29$				X	
DO					
ERROR STATEMENT					X
$S=0.0$	X		X		
$S=T-(329.0+0.29P_v)$		X			
FLUID IS DSS	X				
FLUID IS SS		X			
FLUID IS WSS			X		
RETURN T129	X	X	X	X	

T124 QUALITY OF STEAM

SYSTEM ______ Page ____ of ____

DECISION TABLE

Analyst ______ Date ______

	1	2	3	4	5
$T \leq (370.0 + 0.19P) + 5.$	Y	N	Y	Y	N
$T > (370.0 + 0.19P) - 5.$	Y	Y	N	–	Y
FLUID IS	STM	STM	STM	LIQ	LIQ
$P_V = (T - 370.0) / 0.19$				X	
DO					
ERROR					2
$S = 0.0$	X		X		
$S = T - (370.0 + 0.19P)$		X			
FLUID IS DSS	X				
FLUID IS SS		X			
FLUID IS WSS			X		
RETURN (T129)	X	X	X	X	

T125 QUALITY OF STEAM

SYSTEM ______ Page ______ of ______

DECISION TABLE

Analyst ______
Date ______

	1	2	3	4	5
$T \le (405.0 + 0.14P) + 5.$	Y	N	Y	Y	N
$T > (405.0 + 0.14P) - 5.$	Y	Y	N	—	Y
FLUID IS	STM	STM	STM	LIQ	LIQ
$P_V = (T - 405.0) / 0.14$				X	
DO					
ERROR STATEMENT					X
$S = 0.0$	X		X		
$S = T - (405.0 + 0.14P)$		X			
FLUID IS DSS	X				
FLUID IS SS		X			
FLUID IS WSS			X		
RETURN (T127)	X	X	X	X	

T126 QUALITY OF STEAM

SYSTEM ______ Page ____ of ____

DECISION TABLE

Analyst ✓ Date ______

T ≤ (445.0 + 0.10P) + 5	Y	N	Y	Y	N
T > (445.0 + 0.10P) − 5	Y	Y	N	I	Y
FLUID IS	STM	STM	STM	LIQ	LIQ
PN = (T − 445.0)/0.10				X	
DO					
ERROR STATEMENT					X
S = 0.0	X		X		
S = T − (445.0 + 0.10P)		X			
FLUID IS DSS	X				
FLUID IS SS		X			
FLUID IS WSS			X		
RETURN (T129)	X	X	X	X	

T127 QUALITY OF STEAM

SYSTEM ____________ DECISION TABLE Analyst ____________

Page ______ of ______ Date ____________

T ≤ (476.55+0.08P)+5	Y	N	Y	Y	N
T > (476.55+0.08P)-5	Y	Y	N	-	Y
FLUID IS	STM	STM	STM	LIQ	LIQ
P_V = (T-476.55)/0.08				X	
DO					
ERROR STATEMENT					X
S=1.0	X		X		
S = T-(476.55+0.08P)		X			
FLUID IS DSS	X				
FLUID IS SS		X			
FLUID IS WSS			X		
RETURN (T129)	X	X	X	X	

T128 QUALITY OF STEAM.

SYSTEM______ Page____ of____ **DECISION TABLE** Analyst______ Date______

	1	2	3	4	5
IF $T \le (517.47 + .06 P_A) + 5.$	Y	N	Y	Y	N
IF $T > (517.47 + .06 P_A) - 5.$	Y	Y	N	–	Y
IF FLUID =	STM	STM	STM	LIQ	LIQ
SET $P_U = (T - 517.47)/.06$				X	
SET $S = 0.0$	X		X		
SET $S = T - (517.47 + .06 P_A)$		X			
SET FLUID = DSS	X				
" " = SS		X			
" " = WSS			X		
RETURN (T129)	X	X	X	X	
ERROR STATEMENT					X

T129 QUALITY OF STEAM MANAGEMENT

SYSTEM
DECISION TABLE
Analyst
Page of
Date

FUNCTION: BRANCH DEPENDING UPON PA.

IF Pa ≤	67.01	134.6	247.5	422.6	680.8	1046.
DO table	120	121	122	123	124	125
RETURN (T101)	x	x	x	x	x	x

VARIABLES: Pa : input

T129 (CONTINUED)   QUALITY OF STEAM MANAGEMENT (CONTINUED)

SYSTEM ________ DECISION TABLE Analyst ________
Page ____ of ____ Date ________

IF Pa ≤	1543.	2209.	3499.	—
DO TABLE	126	127	128	
RETURN (129)	X	X	X	
ERROR STATEMENT				X

T300 BODY MATERIAL AND PRESSURE STANDARD MANAGEMENT

SYSTEM ______ DECISION TABLE Analyst ______
Page ______ of ______ Date ______

FUNCTION: BRANCH DEPENDING ON VALUE CLASS

IF CLASS =	1	2	3	4
DO TABLE	310	310	310	311
RETURN (TS)	X	X	X	

T 310 TEST FOR MAXIMUM TEMPERATURE AND PRESSURE

SYSTEM ____________ **DECISION TABLE** Analyst ____________

Page ______ of ______ Date ____________

FUNCTION: CHECK THAT PROCESS CONDITIONS ARE WITHIN LIMITS FOR VALVE CLASS SELECTED

IF T (°F) ≤	-20	600	-
PG ≤	-	6000	-
DO TABLE		320	
ERROR MESSAGE	X		X
RETURN (300)		X	

T311 BODY MATERIAL AND PRESSURE STANDARD MANAGEMENT FOR CLASS 4 VALVES

SYSTEM________ DECISION TABLE Analyst________

Page____ of____ Date________

FUNCTION: NO CONDITION TABLE WHICH PROVIDES A MESSAGE CONCERNING CLASS 4 VALVES.

MESSAGE :	THIS SYSTEM IS NOT COMPLETE FOR CLASS 4 VALVES.

T320 BODY MATERIAL + PRESSURE STANDARD SELECTION

SYSTEM ______ DECISION TABLE Analyst ______

Page ____ of ____ Date ______

FUNCTION: SELECT BDYMAT + PRSTD DEPENDING UPON VALUES OF T AND PG.

IF T ≤	-20.	-20.	150	150	200	200	250	250
IF PG ≤	3600.	6000.	3550.	5715.	3500.	5820.	3450.	5750.
BDYMAT =	CS	CS	CS	CS	CS	CS	CS	CS
BODY PRSTD =	1500	2500	1500	2500	1500	2500	1500	2500
RETURN	X	X	X	X	X	X	X	X

T320-1 (CONTINUED) BODY MATERIAL + PRESSURE STANDARD SELECTION CONTINUED.

SYSTEM ______ **DECISION TABLE** Analyst ______

Page ______ of ______ Date ______

T ≤	300	300	350	350	400	400	450	450
PG ≤	3415.	5620.	3375	5625	3300	5550	3255	5430
BDY MAT =	CS	CS	CS	CS	CS	CS	CS	CS
BODY PRSTD =	1500.	2500.	1500	2500	1500	2500	1500	2500
RETURN	X	X	X	X	X	X	X	X

T320-2 (CONTINUED)

SYSTEM ______ DECISION TABLE Analyst ______
Page ____ of ____ Date ______

IF T ≤	500	500	550	550	600	600	-
IF PG ≤	3125.	5210.	2955.	4225.	2770	4620.	-
BDYMAT =	CS	CS	CS	CS	CS	CS	
PRSTD =	1500	2500	1500	2500	1500	2500	
RETURN	X	X	X	X	X	X	
ERROR MESSAGE							X

T600 VALUE SIZING MANAGEMENT

SYSTEM ______ DECISION TABLE Analyst ______
Page ____ of ____ Date ______

FUNCTION: BRANCH TO SIZING FUNCTIONS DEPENDING UPON FLUID.

IF FLUID =	OIL	GAS	STM	LIQ	SS	10SS	45S	—
DO Table		T601	T601	T502	T601	T601	T601	
DO "				T503				
DO "	T604			T604				
DO "	T605	T605	T605	T605	T605	T605	T605	
ERROR MESSAGE								X
RETURN (OID)	X	X	X	X	X	X	X	

Variables: FLUID: set in table 102, 120 → 128

T601 CALCULATE CRITICAL PRESSURE DROP.

SYSTEM ______ DECISION TABLE Analyst ______

Page ____ of ____ Date ______

FUNCTION: COMPARE PD AGAINST CRITICAL PRESSURE DROP AND DETERMINE CALCULATED PRESSURE DROP.

IF FLUID =	GAS	GAS	WSS	WSS	DSS	DSS	SS	SS
$P_D \le 0.47 P_A$	Y	N						
$P_D \le 0.42 P_A$			Y	N	Y	N		
$P_D \le 0.45 P_A$							Y	N
PDC =	PD	.47 PA	PD	0.42 PA	PD	0.42 PA	PD	0.45 PA
RETURN (TO 600)	X	X	X	X	X	X	X	X

Variable: FLUID: FROM T0102, T0120 + T0128

P_D : input (pressure drop)

P_A : "

PDC : calculated & used in table - - - -

T602 CALCULATED CRITICAL PRESSURE RATIO

SYSTEM ______ DECISION TABLE Analyst ______

Page ____ of ____ Date ______

FUNCTION: DEPENDING UPON THE VALUE OF PV, CALCULATE r_c AND K_m.

IF P_V <	100	300	500	1000	2500	2800	3200	—
SET $r_c = 0.95 - 0.0005\,P_V$	X							
" $r_c = 0.92 - 0.0002\,P_V$		X						
" $r_c = 0.905 - 0.00015\,P_V$			X					
" $r_c = 0.870 - 0.00008\,P_V$				X				
" $r_c = 0.840 - 0.00005\,P_V$					X			
" $r_c = 0.895 - 0.00007\,P_V$						X		
" $r_c = 0.980 - 0.0001\,P_V$							X	
SET $K_m = 0.750$	X	X	X	X	X	X	X	
RETURN	X	X	X	X	X	X	X	
ERROR MESSAGE								X

Variables: P_V: set in TO120 → 128

r_c: also used in TD603

K_m: " " " " TD603

T603 FLASHING LIQUID PRESSURE DROP

DECISION TABLE

SYSTEM ____ Analyst ____

Page ____ of ____ Date ____

FUNCTION: DETERMINE PDC FOR FLASHING LIQUIDS.

	1	2
$PD \leq K_m (P_A - r_c P_V)$	Y	N
$PDC = PD$	X	
$PDC = K_m (P_A - r_c P_V)$		X
RETURN	X	X

Variables:

PD: input

PA: "

PV: from TO120 → 128

rc: TO602

Km: TO602

T604 CALCULATE VISCOSITY CORRECTION FACTOR.

SYSTEM ______ DECISION TABLE Analyst ______
Page ____ of ____ Date ______

FUNCTION: DEPENDING UPON THE VALUE OF VISCOSITY, CALCULATE THE VISCOSITY CORRECTION FACTOR "μ".

VIS ≤	50	100	200	400	1000	2000	3000	—
ERROR	21							22
$\mu = 0.87 + 0.0026$ (VIS)		X						
$\mu = 1.01 + 0.0012$ (VIS)			X					
$\mu = 1.15 + 0.0005$ (VIS)				X				
$\mu = 1.25 + 0.00025$ (VIS)					X			
$\mu = 1.42 + 0.0008$ (VIS)						X		
$\mu = 1.54 + 0.0002$ (VIS)							X	
END	X							X
RETURN		X	X	X	X	X	X	

Variables:

S (viscosity): input

μ (viscosity correction): set & use in table TD605.

T605 Calculate Valve Port Area.

SYSTEM ________ DECISION TABLE Analyst ________

Page ____ of ____ Date ________

FUNCTION: Depending upon fluid, calculate valve port area, and expansion factor.

Fluid is	LIQ	GAS	SS	DSS	NSS	OIL
Y = f(C, ΔP, PA)		X	X	X	X	
A = F(C, W, u, f, SPC, PDC)	X					X
A = F(C, W, S, f, Y, PDC, PA)			X	X	X	
A = F(C, Q, G, T, f, Y, PDC, PA)		X				
RETURN	X	X	X	X	X	X

Variables

FLUID: T0102, T0101, 120 → 128

Y (expansion factor) is calculated.

PD: input

PA: "

u: FROM T0604

F: " T0102 & T0101

SPC = given input

PDC = " "

S = FROM T0120 → T0128

W = MAX. VALVE CAPACITY (LIQ)

Q = MAX. VALVE CAPACITY (GAS)

G = (Specific Gravity) (GAS)

A: also used in 608, 624, 670, 1002.

T606 SELECT CLASS DEPENDING ON VALVE POSITION

SYSTEM 4 DECISION TABLE Analyst

Page of Date

FUNCTION : RESET CLASS DEPENDING ON VALUE POSITION AND BRANCH TO SIZING

T0606							
CLASS SELECTED =	1	1	1	2	8	3	4
T ≤ 600°F	Y	N	N	Y	N	–	–
VLV POS =		NO	NC				
ERROR		25	25		26		
PLUG = 7130142-1			X				
PLUG. = 7130142-2		X					
PLUG = 7131556-1	X						
SELECT CLASS	5	6	6	8	7		
DO TABLE	T0608	T0608	T0608	T0613a	T0609a	T0619a	
DO TABLE	T0643	T0643	T0643	T0643	T0643	T0643	
DO T680							X
RETURN (010)	X	X	X	X	X	X	X

VARIABLES:

CLASS : FROM T0101 + 102

VLV POS : INPUT

T : INPUT

PLUG : SET + USE IN TABLE

CLASS : SET + USE IN TABLE

T607 COMPARE MAXIMUM PROCESS FLOW TO MAXIMUM VALUE CAPACITY

SYSTEM ______ DECISION TABLE Analyst ______

Page ____ of ____ Date ______

FUNCTION: COMPARE MAX. PROCESS FLOW TO MAX VALUE CAPACITY FROM T608.

W ≤ F(DP)	Y	N
DO	T0607a	
ERROR MESSAGE.		
RETURN	X	
SET SELROU = 2		X
GO TO		T0101

W: input

FDP: from T0608

SELROU: set & use in T0101

T607A CALCULATE AREA AND DIAMETER OF VALVE INLET AND OUTLET

SYSTEM ______ DECISION TABLE Analyst ______
Page ____ of ____ Date ______

FUNCTION: DEPENDING ON MAXIMUM CAPACITY REQUIREMENTS CHOSE ID = OD AND CALCULATE AI AND AO.

W ≤	45,000	90,000	120,000	150,000	175,000	200,000
SET ID =	1.00	1.25	1.50	2.00	2.50	3.00
SET OD =	1.00	1.25	1.50	2.00	2.50	3.00
$AI = 3.14(ID/2)^2$	X	X	X	X	X	X
AO = AI	X	X	X	X	X	X
RETURN	X	X	X	X	X	X

W: input

ID set & use 607a
OD " " " 607a

AI: set & use —
AO: " " " —

T608 CALCULATE MAXIMUM VALVE CAPACITY

DECISION TABLE

No. ____ of ____ Analyst ____ Date ____

FUNCTION: CALCULATE MAXIMUM VALVE CAPACITY AS A FUNCTION OF PD AND PORT AREA

PD ≤	100	400	610	800	-
A ≤	0.601	0.601	0.601	0.601	-
SELROW=SELROW+1					X
W_1 =	36000	73000	141000	175000	
DP_1 =	25	100	400	610	
W_2 =	73000	141000	175000	200000	
DP_2 =	100	400	610	800	
FDP=F(W_1, W_2, DP_1, DP_2)	X	X	X	X	
ERROR MESSAGE					X
DO TO607	X	X	X	X	
RETURN (606)	X	X	X	X	
GO TO					T101A

PD = INPUT

A = FROM 605

W = MAX VALVE CAPACITY (INPUT)

W_1 = SET & USED 608

W_2 = SET & USED 608

DP_1 = SET & USED 608

DP_2 = SET & USED 608

SELROW = SET & USED TO608

T.609A Class 2 Linear Velocity Calculations

SYSTEM ______ DECISION TABLE Analyst ______

Page ____ of ____ Date ______

FUNCTION: NO CONDITION TABLE GIVING A MESSAGE

MESSAGE:	THIS SYSTEM IS NOT COMPLETE FOR CLASS 2 VALUES

T613A CLASS 3 LINEAR VELOCITY CALCULATIONS

SYSTEM ______ DECISION TABLE Analyst ______

Page ____ of ____ Date ______

FUNCTION: NO CONDITION TABLE GIVEN MESSAGE.

MESSAGE :	THIS SYSTEM IS NOT COMPLETE FOR CLASS 3 VALUES

T619A CLASS 4 LINEAR VELOCITY CALCULATIONS

SYSTEM ______ DECISION TABLE Analyst ______

Page ______ of ______ Date ______

FUNCTION: NO CONDITION TABLE, GIVING MESSAGE.

MESSAGE:	THIS SYSTEM IS NOT COMPLETE FOR CLASS 4 VALUES.

T643 CALCULATE LINEAR VELOCITY

SYSTEM ______ DECISION TABLE Analyst ______

Page ______ of ______ Date ______

FUNCTION: DEPENDING UPON FLUID CALCULATE LINEAR VELOCITY

FLUID IS	GAS	LIQ	STM	SS	USS	VSS	—
VI = F(C, W, AI, SPC)		X					
VO = F(C, W, AO, SPC)	X						
VO = F(C, W, AO, SPC)			X				
DO TABLE	TO644	TO645	TO644	[illegible]	[illegible]	[illegible]	
RETURN	X	X	X				
ERROR MESSAGE							X

SPC: specific wgt

W: input

Ai: from TO624 TO 642.

FLUID: from TO101, TO102.

SPC - input

T644 Check Linear Velocity Limit

SYSTEM ____ Page ____ of ____

DECISION TABLE

Analyst ____ Date ____

T0649		
$V_0 < 50{,}000$	Y	N
ERROR		30
RETURN MESSAGE	X	

T645 CHECK INLET LINEAR VELOCITY LIMITATIONS

SYSTEM ____________ Page ______ of ______

DECISION TABLE

Analyst ____________ Date ____________

	1	2
$V_i < 2100$	Y	N
CLASS SELECTED	4	4
ERROR MESSAGE		X
RETURN	X	

T680 CLASS 4 VALUE SIZING

SYSTEM________ DECISION TABLE Analyst________

Page______ of______ Date________

FUNCTION: NO CONDITION TABLE, GIVING MESSAGE CONCERNING CLASS 4 VALUES

MESSAGE:	This system is not complete for Class 4 values.

T 1000 ACTUATOR SELECTION MANAGEMENT.

SYSTEM ________ DECISION TABLE Analyst ________
Page ____ of ____ Date ________

FUNCTION: BRANCH TO ACTUATOR SELECTION ROUTINE DEPENDING UPON VALUE CLASS.

CLASS SELECTED =	7	5	7	8	3	
DO	T1001	T1001	T1002	T1004	T1006	
ERROR MESSAGE.						X
RETURN ([illegible])	X	X	X	X	X	

Variables:

Class: from T0101, 102

T1001 ACTUATOR SELECTION

SYSTEM ______ DECISION TABLE Analyst ______

Page ______ of ______ Date ______

FUNCTION: SELECT ACTUATOR SIZE AS A RESULT OF VALVE POSITION AND INLET PRESSURE.

T1001				
IF VLVPOS = NO	Y	Y	N	N
PA ≤	36/15	58/15	36/15	55/15
SET ACT =	60	70	60	70
ERROR MESSAGE				
RETURN	X	X	X	X

VLVPOS = input

P.A = input

ACT: set & use in Table

T1200 VALUE SPECIFICATION OUTPUT

SYSTEM ______ DECISION TABLE Analyst ______
Page ____ of ____ Date ______

FUNCTION: ND CONDITION TABLE GIVING SYSTEM OUTPUT

```
∇T1200[□]∇
  ∇ T1200
[1]   '               VALUE SPECIFICATIONS'
[2]   '               ********************'
[3]   '
[4]   'ITEM NUMBER:              QUANTITY:'
[5]   'SERVICE:';SERV
[6]   '
[7]   '
[8]   'BODY-SIZE    :';AO;'  INS'
[9]   'CLASS        :';CLASS
[10]  'FLUID        :';FLUID
[11]  'CAPACITY     :';W;'   LBS/HR    ';Q;'   SCHF'
[12]  'INLET PRES   :';PA;'  PSIA'
[13]  'PRES DROP    :';PD;'  PSI'
[14]  'TEMPERATURE  :';T;'   DEGREES F'
[15]  'SP GRAVITY   :';SPG
[16]  '
[17]  '
[18]  'BODY PRESSURE STANDARD:';PRSTD
[19]  'BODY MATERIAL          :';BDYMAT
[20]  'ACTUATOR SIZE          :';ACT
[21]  '
[22]  '
[23]  'ACCESSORIES:'
[24]  '
[25]  '
[26]  '
[27]  'SHIPPING WGT:'
[28]  'AIR CONSUMPTION:'
[29]  'REMARKS:'
[30]  '
[31]  '
[32]  '
[33]  T1201
```

T1201 VALUE PRICE MAKE-UP OUTPUT

SYSTEM ______ DECISION TABLE Analyst ______
Page ___ of ___ Date ______

FUNCTION: NO CONDITION TABLE GIVING SYSTEM OUTPUT.

```
∇T1201[□]∇
    ∇ T1201
[1]    '              VALUE PRICE MAKE UP'
[2]    '              *******************'
[3]    '
[4]    '
[5]    'ITEM NUMBER:                QUANTITY:'
[6]    '
[7]    '
[8]    '       DESCRIPTION                          PRICE'
[9]    '
[10]   'BODY      PRESSURE STANDARD:  ;PRSTD
[11]   '          MATERIAL            ;BDYMAT
[12]   '
[13]   'ACTUATOR             SIZE  : ;ACT;
[14]   '
[15]   'ACCESSORIES
[16]   '
[17]   '
[18]   'SHIPPING WEIGHT
[19]   '
[20]   '
[21]   '                            TOTAL PRICE
[22]   '                          x QUANTITY
    ∇
```

APPÆNDIX D.

SYSTEM PROGRAMS.

D.1. FUNCTION LIST.

```
)FNS
STA      START    TERMINATE    T1      T1000   T1001   T101    T101A   T1
20       T1200    T1201    T121    T122    T123
T124     T125     T126     T127    T128    T129    T2      T3      T300    T3
10       T311     T4       T5      T600    T601
T602     T603     T604     T605    T606    T607    T607A   T608    T609A   T6
13A      T619A    T643     T644    T646    T680
```

D.2. SYSTEM FUNCTIONS.

```
∇START[□]∇
    ∇ START;MODE;Y
[1]    →2
[2]    '

                     COMPUTER ASSISTED PROPOSAL PREPARATION'
[3]    '
[4]    '                               FOR'
[5]    '                       CLASS 1, 2, 3 VALUES'
[6]    '                     * VERSION 1 * MAY 1973 *'
[7]    '


                                  MODE SELECTION'
[8]    '                                 **************'
[9]    '      FOR SYSTEM DESCRIPTION TYPE                    :T1'
[10]   '      FOR OPERATION DESCRIPTION TYPE                 :T2'
[11]   '      FOR LIST OF INPUT VARIABLES TYPE               :T3'
[12]   '      FOR SAMPLE RUN TYPE                            :T4'
[13]   '      FOR EXECUTION TYPE                             :T5'
[14]   '      FOR TERMINATION TYPE                           :TERMINATE'
[15]   STA
    ∇


    ∇STA[□]∇
    ∇ STA;MODE;Y
[1]    '

              ENTER MODE'
[2]    MODE←□
[3]    MODE
[4]    →
[5]    →
    ∇
```

```
∇T1[⎕]∇
    ∇ T1
[1]   '                    SYSTEM DESCRIPTION'
[2]   '                    ******************'
[3]   ' '
[4]   ' '
[5]   'THE PURPOSE OF A COMPUTER ASSISTED PROPOSAL PREPARATION'
[6]   'SYSTEM , CAPP , IS TO PROVIDE AN EFFICIENT MEANS OF'
[7]   'PREPARING CONTROL SYSTEM VALVE PROPOSALS. THE USER'
[8]   'MUST ANALYSE AND INTERPRET THE CUSTOMER SPECIFICATIONS'
[9]   'AND DEFINE THE SERVICE CONDITIONS AFFECTING THE EQUIPMENT'
[10]  'SELECTION. USING THESE CONDITIONS AS INPUTS, CAPP WILL'
[11]  'THEN PERFORM EQUIPMENT SELECTION AND PROVIDE A PRINTOUT'
[12]  'OF EQUIPMENT DOCUMENTATION AND PRICING.'
[13]  STA
    ∇

    ∇T2[⎕]∇
    ∇ T2
[1]   '                    SYSTEM OPERATION'
[2]   '                    ****************'
[3]   ' '
[4]   ' '
[5]   'CAPP IS DESIGNED WITH USER CONVIENCE IN MIND. USING THE'
[6]   'SYSTEM SIMPLY CONSISTS OF PROVIDING ANSWERS TO THE'
[7]   'QUESTIONS ASKED. THE SYSTEM CHECKS THE VALUES ENTERED TO'
[8]   'VERIFY THAT THEY ARE WITHIN ALLOWABLE LIMITS. A COMPLETE'
[9]   'LIST OF SYSTEM VARIABLES IS GIVEN IN MODE T3, AND A SAMPLE'
[10]  'SESSION IS GIVEN IN MODE T4. REFER TO THE SYSTEM USERS'
[11]  'MANUAL FOR A COMPLETE DESCRIPTION OF SYSTEM OPERATION.'
[12]  STA
    ∇
```

```
     ∇ T3
[1]   '                     SYSTEM VARIABLES'
[2]   '                     ****************'
[3]   '
[4]   '
[5]   '                     INPUT VARIABLES'
[6]   '
[7]   '
[8]   'SYMBOL      DESCRIPTION              FUNCTION         UNITS'
[9]   '
[10]  'SERV   VALVE SERVICE                  T101    1:ATOMIZING STEAM SHUT OFF'
[11]  '                                              2:BOILER AUXILLIARIES'
[12]  '                                              3:DESUPERHEATER WATER SPRAY'
[13]  '                                              4:FEEDWATER FLOW'
[14]  '                                              5:HEATER LEVEL CONTROL'
[15]  '                                              6:OIL SHUT OFF'
[16]  '                                              7:OIL BURNER CONTROL'
[17]  '                                              8:PUMP RECIRC SHUT OFF'
[18]  '                                              9:SUPERHEATER SPRAY CONTROL'
[19]  '                                             10:REHEAT SPRAY CONTROL'
[20]  '                                             11:SUPERHEATER SPRAY SHUT OFF'
[21]  '                                             12:REHEAT SPRAY SHUT OFF'
[22]  '                                             13:STEAM PRESSURE REDUCING'
[23]  'T      FLUID TEMPERATURE              T101         DEGREES F'
[24]  'PA     STATIC INLET PRESSURE          T129         PSIA'
[25]  'PD     PRESSURE DROP                  T600         PSI'
[26]  'VIS    VISCOSITY                      T604         SSU'
[27]  'W      MAX VALVE CAPACITY(LIQ)        T605         LBS/HR'
[28]  'SPC    SPECIFIC GRAVITY(LIQ)          T605
[29]  'Q      MAX VALVE CAPACITY(GAS)        T605         SCHF'
[30]  'G      SPECIFIC GRAVITY(GAS)          T605'
[31]  'VLVPOS VALVE POSITION                 T606    NO:NORMALLY OPEN'
[32]  '                                              NC:NORMALLY CLOSED'
[
    ∇T4[□]∇

     ∇ T4
[1]   '                     SAMPLE SESSION'
[2]   '                     **************'
[3]   '
[4]   'FOR A COMPLETE EXAMPLE OF A SYSTEM SESSION REFER TO'
[5]   'THE CARP USERS MANUAL'
[6]   STA
     ∇

     ∇T5[□]∇
     ∇ T5
[1]   SELROU←1
[2]   T101
[3]   T300
[4]   T600
[5]   T606
[6]   T1200
     ∇

     ∇TERMINATE[□]∇
     ∇ TERMINATE
[1]   'THIS SESSION IS TERMINATING ; TO RESTART TYPE START OR ENTER MODE'
[2]   SELROU←SERV←CLASS←FLUID←F←SX←PV←T←PA←PG←PRSTD←BDYMAT←PD←PDC←0
[3]   RC←KM←VIS←U←W←SPC←Q←G←ID←OD←AI←AO←FDP←VO←VI←VLVPOS←ACT←0
[4]   →
     ∇
```

```
∇T101[⎕]∇
    ∇ T101;S;A;W;U;V
[1]   S←1
[2]   'ENTER SERVICE'
[3]   SERV←⎕
[4]   A←(14=((1 2 3 4 5 6 7 8 9 10 11 12 13)⍳SERV))
[5]   →11-A×5
[6]   'SERVICE ENTERED NOT VALID; TRY AGAIN'
[7]   →8+(4=S←(S+1))
[8]   →2
[9]   'ERROR NUMBER 8; TABLE 101'
[10]  →TERMINATE
[11]  W← 1 2 2 4 4 1 2 1 2 2 1 1 2 0
[12]  CLASS←W[SERV]
[13]  V← 1 1 2 2 2 3 3 2 [illegible] 2 2 2 1 0
[14]  FLUID←V[SERV]
[15]  U← 0.65 0.65 0.65 0.5 0.5 0.65 0.65 0.65 0.65 0.65 0.65 0.65 0.65 0
[16]  F←U[SERV]
[17]  S←3=FLUID
[18]  →19+S
[19]  T129
    ∇
```

```
∇T101A[⎕]∇
    ∇ T101A;X;Z;X1;W;V;U;S
[1]   X← 3 9 10 13
[2]   Z←X⍳SERV
[3]   X1←5=Z
[4]   →5+X1×10
[5]   W← 3 3 3 4
[6]   CLASS←W[Z]
[7]   V← 2 2 2 1
[8]   FLUID←V[Z]
[9]   U← 0.65 0.65 0.65 0.5
[10]  F←U[Z]
[11]  S←3=FLUID
[12]  →13+S
[13]  T129
[14]  →17
[15]  'ERROR NUMBER 8 ; TABLE 101A'
[16]  →TERMINATE
    ∇
```

```
∇T120[⎕]∇
    ∇ T120;X;Y;X1;X2;Z;W;S1;PV1
[1]   X←T≤((187+1.68×PA)+5)
[2]   Y←T>((187+1.68×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ⍴X1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ⍴X2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(187+1.68×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PV1← 22 22 23
[20]  PV1←PV1[Z]
[21]  →PV1
[22]  PV←(T-187)÷1.68
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
                 ERROR NO 2: TABLE 120'
[26]  →TERMINATE
    ∇

∇T121[⎕]∇
    ∇ T121;X;Y;X1;X2;Z;W;S1;PV1
[1]   X←T≤((250.4+0.74×PA)+5)
[2]   Y←T>((250.4+0.74×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ⍴X1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ⍴X2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(250.4+0.74×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PV1← 22 22 23
[20]  PV1←PV1[Z]
[21]  →PV1
[22]  PV←(T-250.4)÷0.74
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
                 ERROR NO 2: TABLE 121'
[26]  →TERMINATE
    ∇
```

```
∇T122[⎕]∇
    ∇ T122;X;Y;X1;X2;Z;W;S1;PV1
[1]   X←T≤((301.54+0.36×PA)+5)
[2]   Y←T>((301.54+0.36×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ⍴X1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ⍴X2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(301.54+0.36×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PV1← 22 22 23
[20]  PV1←PV1[Z]
[21]  →PV1
[22]  PV←(T-301.54)÷0.36
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
                    ERROR NO 2: TABLE 122'
[26]  →TERMINATE
    ∇

∇T123[⎕]∇
    ∇ T123;X;Y;X1;X2;Z;W;S1;PV1
[1]   X←T≤((329+0.29×PA)+5)
[2]   Y←T>((329+0.29×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ⍴X1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ⍴X2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(329+0.29×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PV1← 22 22 23
[20]  PV1←PV1[Z]
[21]  →PV1
[22]  PV←(T-329)÷0.29
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
                    ERROR NO 2: TABLE 123'
[26]  →TERMINATE
[27]  →28
    ∇
```

```
∇T124[⎕]∇
    ∇ T124;X;Y;X1;X2;Z;W;S1;PU1
[1]   X←T≤((370+0.19×PA)+5)
[2]   Y←T>((370+0.19×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ρX1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ρX2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(370+0.19×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PU1← 22 22 23
[20]  PU1←PU1[Z]
[21]  →PU1
[22]  PU←(T-370)÷0.19
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
                ERROR NO 2; TABLE 124'
[26]  →TERMINATE
    ∇

∇T125[⎕]∇
    ∇ T125;X;Y;X1;X2;Z;W;S1;PU1
[1]   X←T≤((405+0.14×PA)+5)
[2]   Y←T>((405+0.14×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ρX1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ρX2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(405+0.14×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PU1← 22 22 23
[20]  PU1←PU1[Z]
[21]  →PU1
[22]  PU←(T-405)÷0.14
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
                ERROR NO 2; TABLE 125'
[26]  →TERMINATE
    ∇
```

```
∇T126[⎕]∇
    ∇ T126;X;Y;X1;X2;Z;W;S1;PV1
[1]   X←T≤((445+0.1×PA)+5)
[2]   Y←T>((445+0.1×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ⍴X1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ⍴X2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(445+0.1×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PV1← 22 22 23
[20]  PV1←PV1[Z]
[21]  →PV1
[22]  PV←(T-445)÷0.1
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
              ERROR NO 2; TABLE 126!
[26]  →TERMINATE
    ∇
```

```
∇T127[⎕]∇
    ∇ T127;X;Y;X1;X2;Z;W;S1;PV1
[1]   X←T≤((476.550000000001+0.08×PA)+5)
[2]   Y←T>((476.550000000001+0.08×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ⍴X1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ⍴X2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(476.550000000001+0.08×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PV1← 22 22 23
[20]  PV1←PV1[Z]
[21]  →PV1
[22]  PV←(T-476.550000000001)÷0.08
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
              ERROR NO 2; TABLE 127!
[26]  →TERMINATE
    ∇
```

```
∇T128[⎕]∇
    ∇ T128;X;Y;X1;X2;Z;W;S1;PU1
[1]   X←T≤((517.4700000000001+0.06×PA)+5)
[2]   Y←T≥((517.4700000000001+0.06×PA)-5)
[3]   X1←X,Y
[4]   X1← 3 2 ⍴X1
[5]   X2← 1 1 1 0 0 1
[6]   X2← 3 2 ⍴X2
[7]   Y←X1=X2
[8]   Y←Y[;1]∧Y[;2]
[9]   Z←Y⍳1
[10]  W←FLUID=2
[11]  →12+W×7
[12]  S1← 16 16 15
[13]  S1←S1[Z]
[14]  →S1
[15]  SX←T-(517.4700000000001+0.06×PA)
[16]  X← 4 5 6
[17]  FLUID←X[Z]
[18]  →27
[19]  PU1← 22 22 23
[20]  PU1←PU1[Z]
[21]  →PU1
[22]  PV←(T-517.4700000000001)÷0.06
[23]  Y←3=Z
[24]  →27-Y×2
[25]  '
                        ERROR NO 2; TABLE 128'
[26]  →TERMINATE
    ∇

∇T129[⎕]∇
    ∇ T129;S;X;A;Z
[1]   S←1
[2]   'ENTER STATIC INLET PRESSURE ; PSIA'
[3]   PA←⎕
[4]   X←PA>3199
[5]   →13-X×7
[6]   'STATIC INLET PRESSURE > CRITICAL PRESSURE'
[7]   S←S+1
[8]   A←4=S
[9]   →A+10
[10]  →2
[11]  'ERROR NO 1 ; TABLE 129'
[12]  →TERMINATE
[13]  'ENTER TEMPERATURE ; OF'
[14]  T←⎕
[15]  A← 67.01000000000001 134.6 247.3 422.6000000000001 680.8000000000001
 1046 1543 2209 3199
[16]  A←PA>A
[17]  A←+/A
[18]  Z← 21 23 25 27 29 31 33 35 37
[19]  Z←Z[A]
[20]  →Z
[21]  T120
[22]  →38
[23]  T121
[24]  →38
[25]  T122
[26]  →38
[27]  T123
[28]  →38
[29]  T124
[30]  →38
[31]  T125
[32]  →38
[33]  T126
[34]  →38
[35]  T127
[36]  →38
[37]  T128
    ∇
```

```
∇T300[⎕]∇
     ∇ T300;X;Y
[1]    X← 1 2 3 4
[2]    X←CLASS=X
[3]    X←X⍳1
[4]    Y← 7 7 7 9 11
[5]    Y←Y[X]
[6]    →Y
[7]    T310
[8]    →13
[9]    T311
[10]   →13
[11]   '
                 NO 3  ERROR TABLE 300'
[12]   →TERMINATE
     ∇
```

```
∇T310[⎕]∇
     ∇ T310;X1;X2;X3
[1]    PG←PA-14.5
[2]    X1←PG≤6000
[3]    →14-X1×10
[4]    X2←(+/(~(T≤ 0 1200)))+1
[5]    X3← 7 9 11
[6]    →X3[X2]
[7]    '
                 ERROR NO 4: TABLE 310'
[8]    →13
[9]    T320
[10]   →16
[11]   '
                 ERROR NO 5: TABLE 310'
[12]   →13
[13]   →TERMINATE
[14]   '
                 ERROR NO 6: TABLE 310'
[15]   →13
     ∇
```

```
     ∇T311[⎕]∇
   ∇ T311
[1]   '
              FOR THE SERVICE CONDITIONS ENTERED, A D10 VALUE WOULD BE SELE
CTED.'
[2]   'HOWEVER, THIS SYSTEM IS NOT COMPLETED FOR D10 VALUES'
[3]   →TERMINATE
   ∇
```

```
∇T320[⎕]∇
    ∇ T320;X1;X2;X3;X4;X5;X6
[1]   X1← 0 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800
[2]   X2← 850 875 900 925 950 975 1000 1025 1050 1075 1100 1150 1200
[3]   X1←X1,X2
[4]   X1←(+/(~(T≤X1)))+1
[5]   X2←29=X1
[6]   →7+X2×67
[7]   X3← 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

[8]   X4← 53 55 57 59 61 63
[9]   X3←X3,X4
[10]  →X3←X3[X1]
[11]  X4←(+/(~(PG≤ 3600 6000)))+1
[12]  →66
[13]  X4←(+/(~(PG≤ 3550 5915)))+1
[14]  →66
[15]  X4←(+/(~(PG≤ 3500 5830)))+1
[16]  →66
[17]  X4←(+/(~(PG≤ 3450 5750)))+1
[18]  →66
[19]  X4←(+/(~(PG≤ 3415 5690)))+1
[20]  →66
[21]  X4←(+/(~(PG≤ 3375 5625)))+1
[22]  →66
[23]  X4←(+/(~(PG≤ 3300 5550)))+1
[24]  →66
[25]  X4←(+/(~(PG≤ 3255 5430)))+1
[26]  →66
[27]  X4←(+/(~(PG≤ 3125 5210)))+1
[28]  →66
[29]  X4←(+/(~(PG≤ 2955 4925)))+1
[30]  →66
[31]  X4←(+/(~(PG≤ 2770 4620)))+1
[32]  →66
[33]  X4←(+/(~(PG≤ 2580 4300)))+1
[34]  →66
[35]  X4←(+/(~(PG≤ 2415 4025)))+1
[36]  →66
[37]  X4←(+/(~(PG≤ 2250 3745)))+1
[38]  →66
[39]  X4←(+/(~(PG≤ 2080 3470)))+1
[40]  →66
[41]  X4←(+/(~(PG≤ 1915 3190)))+1
[42]  →66
[43]  X4←(+/(~(PG≤ 1830 3055)))+1
[44]  →66
[45]  X4←(+/(~(PG≤ 1750 2915)))+1
[46]  →66
[47]  X4←(+/(~(PG≤ 1665 2775)))+1
[48]  →66
[49]  X4←(+/(~(PG≤ 1585 2640)))+1
[50]  →66
[51]  X4←(+/(~(PG≤ 1500 2500)))+1
[52]  →66
[53]  X4←(+/(~(PG≤ 1250 2085)))+1
[54]  →66
[55]  X4←(+/(~(PG≤ 1070 1785)))+1
[56]  →66
[57]  X4←(+/(~(PG≤ 890 1485)))+1
[58]  →66
[59]  X4←(+/(~(PG≤ 730 1215)))+1
[60]  →66
[61]  X4←(+/(~(PG≤ 565 945)))+1
[62]  →66
[63]  X4←(+/(~(PG≤ 375 630)))+1
[64]  →66
[65]  X4←(+/(~(PG≤ 255 430)))+1
[66]  X5←3=X4
[67]  →68+X5×4
[68]  X6← 1500 2500
[69]  PRSTD←X6[X4]
[70]  BDYMAT←1
[71]  →76
[72]  '
                              ERROR NO 5 : TABLE 320'
[73]  →TERMINATE
[74]  '
                              ERROR NO 6 :TABLE 320'
[75]  →TERMINATE
```

```
∇T600[⎕]∇
    ∇ T600;X;X1;Y;S
[1]   S←1
[2]   'ENTER PRESSURE DROP ; PSI'
[3]   PD←⎕
[4]   →5+(PD≤2000)×5
[5]   'PRESSURE DROP EXCEEDS MAX OF 2000 PSI ; TRY AGAIN'
[6]   →7+(4=S←(S+1))
[7]   →2
[8]   'ERROR NO   ; TABLE 601'
[9]   →TERMINATE
[10]  X← 3 7 1 2 6 4 5
[11]  X1←(FLUID=X)⍳1
[12]  Y← 15 18 18 21 18 18 18 26
[13]  Y←Y[X1]
[14]  →Y
[15]  T604
[16]  T605
[17]  →28
[18]  T601
[19]  T605
[20]  →28
[21]  T602
[22]  T603
[23]  T604
[24]  T605
[25]  →28
[26]  ' ERROR NO 8 ; TABLE 600'
[27]  →TERMINATE
    ∇

∇T601[⎕]∇
    ∇ T601;X1;P;S
[1]   X1←(FLUID=(7 5 4 6))⍳1
[2]   P← 0.47 0.42 0.42 0.45
[3]   →4+(PD≥(P[X1]×PA))×2
[4]   PDC←PD
[5]   →8
[6]   S← 0.47 0.42 0.42 0.47
[7]   PDC←(S[X1])×PA
    ∇

    ∇T603[⎕]∇
    ∇ T603
[1]   →2+(PD≤(KM×(PA-RC×PU)))×2
[2]   PDC←KM×(PA-RC×PU)
[3]   →5
[4]   PDC←PD
    ∇
```

```
∇T604[⎕]∇
    ∇ T604;S;X;Y;U1;U2
[1]    S←1
[2]    'ENTER VISCOSITY; SSU'
[3]    VIS←⎕
[4]    →5+(VIS≤3000)×5
[5]    'VISCOSITY ENTERED EXCEEDS MAXIMUM OF 3000 SSU; TRY AGAIN'
[6]    →7+(4=S←(S+1))
[7]    →2
[8]    'ERROR NUMBER 22; TABLE 604'
[9]    →TERMINATE
[10]   →11+(VIS≥50)×5
[11]   'VISCOSITY ENTERED LESS THAN MINIMUM OF 50 SSU; TRY AGAIN'
[12]   →13+(4=S←(S+1))
[13]   →2
[14]   'ERROR NUMBER 21; TABLE 604'
[15]   →TERMINATE
[16]   X← 50 100 200 400 1000 2000 3000
[17]   Y←(+/(~(VIS<X)))+1
[18]   U1← 0.87 1.01 1.15 1.25 1.42 1.54
[19]   U2← 0.002600000000000001 0.0012 0.0005000000000000001 0.00025 8.0000
00000000002E¯5 2.000000000000001E¯5
[20]   U←U1[Y]+U2[Y]×VIS
    ∇


∇T605[⎕]∇
    ∇ T605;X;X2
[1]    X←((FLUID=(2 7 6 4 5 3))⍳1)
[2]    →3+(1=X)
[3]    →4+(6=X)
[4]    Y←0.9970000000000001-(0.5310000000000001×(PD+PA))
[5]    X2← 7 17 13 13 13 7
[6]    →X2[X]
[7]    'ENTER MAXIMUM VALUE CAPACITY; LBS/HR'
[8]    W←⎕
[9]    'ENTER SPECIFIC GRAVITY OF FLUID'
[10]   SPC←⎕
[11]   A←([redacted])+([redacted]×([redacted]C)×[redacted])
[12]   →22
[13]   'ENTER MAXIMUM VALUE CAPACITY; LBS/HR'
[14]   W←⎕
[15]   A←([redacted])+([redacted]×([redacted])×[redacted]))
[16]   →22
[17]   'ENTER MAXIMUM VALUE CAPACITY; SCFH'
[18]   Q←⎕
[19]   'ENTER SPECIFIC GRAVITY OF GAS'
[20]   G←⎕
[21]   A←([redacted])×(([redacted]))+([redacted]))×[redacted]
    ∇
```

```
∇T606[⎕]∇
    ∇ T606;X;X1;X2;X3;Z;Z1
[1]   X← 1 1 1 0 2 1 2 0 3 1 3 0 4 1 4 0
[2]   X← 8 2 ⍴X
[3]   X1←T⍳600
[4]   X2←CLASS,X1
[5]   X2← 8 2 ⍴X2
[6]   X3←X=X2
[7]   X3←X3[;1]∧X3[;2]
[8]   Z←X3⍳1
[9]   Z1← 12 14 16 19 22 22 24 24
[10]  Z1←Z1[Z]
[11]  →Z1
[12]  CLASS←5
[13]  →26
[14]  CLASS←6
[15]  →26
[16]  CLASS←7
[17]  T613A
[18]  →27
[19]  CLASS←8
[20]  T609A
[21]  →27
[22]  T619A
[23]  →27
[24]  T680
[25]  →29
[26]  T608
[27]  T643
[28]  T1000
    ∇
```

```
∇T607[⎕]∇
    ∇ T607;X
[1]   X←W⍳FDP
[2]   →3+X×2
[3]   T607A
[4]   →8
[5]   'MESSAGE NUMBER 4; TABLE 607'
[6]   SELROU←SELROU+1
[7]   →T101A
    ∇
```

```
∇T607A[⎕]∇
    ∇ T607A;X;X1;X2;X3;X4
[1]   X1←(+/(~(W⍳(45000 90000 120000 150000 175000 200000))))+1
[2]   X2←6=X1
[3]   →4+X2×6
[4]   X3← 1 1.25 1.5 2 2.5 3
[5]   ID←X3[X1]
[6]   OD←ID
[7]   AI←3.140000000000001×((ID÷2)*2)
[8]   AO←AI
[9]   →12
[10]  'ERROR NUMBER 9 ; TABLE 607A'
[11]  →TERMINATE
    ∇
```

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```
∇T608[⎕]∇
    ∇ T608;X2;X3;X4;W1;DP1;W2;DP2
[1]    →2
[2]    X2←(+/(~(PD≤(100 400 610 800))))+1
[3]    →4+((5=X2)×11)
[4]    X4← 36000 73000 141000 175000
[5]    W1←X4[X2]
[6]    X4← 25 100 400 610
[7]    DP1←X4[X2]
[8]    X4← 73000 141000 175000 200000
[9]    W2←X4[X2]
[10]   X4← 100 400 610 800
[11]   DP2←X4[X2]
[12]   FDP←(((W1×DP2)-(W2×DP1))+((W1-W2)×PD))÷(DP2-DP1)
[13]   T607
[14]   →18
[15]   'ERROR NUMBER 29; TABLE 608'
[16]   SELROU←SELROU+1
[17]   →T101A
    ∇
```

```
∇T609A[⎕]∇
    ∇ T609A
[1]    'THIS SYSTEM IS NOT COMPLETE FOR SIZING A11 VALUES.'
[2]    →TERMINATE
    ∇
```

```
∇T613A[⎕]∇
    ∇ T613A
[1]    'THIS SYSTEM IS NOT COMPLETED FOR SIZING A11 VALUES.'
[2]    →TERMINATE
    ∇
```

```
∇T619A[⎕]∇
    ∇ T619A
[1]    'THIS SYSTEM IS NOT COMPLETE FOR SIZING A13 VALUES.'
[2]    →TERMINATE
    ∇
```

```
∇T643[⎕]∇
    ∇ T643;X;X1;X2;X3;X4
[1]   X← 7 2 1 6 4 5
[2]   X1←FLUID=X
[3]   X2←X1⍳1
[4]   X3← 7 10 13 13 13 13 16
[5]   X4←X3[X2]
[6]   →X4
[7]   VO←(2.4×W)+(AO×SPC)
[8]   T644
[9]   →18
[10]  VI←(0.04×W)+(AI×SPC)
[11]  T645
[12]  →18
[13]  VO←(2.4×W×SP×VO)+AO
[14]  T644
[15]  →18
[16]  'ERROR NUMBER 8 ; TABLE 643'
[17]  →TERMINATE
    ∇

∇T644[⎕]∇
    ∇ T644;X
[1]   X←VO<50000
[2]   →5-X×2
[3]   'ERROR NUMBER 10; TABLE 644'
[4]   →TERMINATE
    ∇

∇T645[⎕]∇
    ∇ T645;X;X1
[1]   X←4=CLASS
[2]   →7-X×4
[3]   X1←VI<2100
[4]   →7-X1×3
[5]   'ERROR NUMBER 11; TABLE 645'
[6]   →TERMINATE
    ∇

∇T680[⎕]∇
    ∇ T680
[1]   'THIS SYSTEM IS NOT COMPLETED FOR SIZING D10 VALUES.'
[2]   →TERMINATE
    ∇
```

```
∇T1000[⎕]∇
     ∇ T1000;X;X1;X2;X3
[1]    X← 6 5 8 7 3
[2]    X1←CLASS=X
[3]    X2←X1⍳1
[4]    X3← 7 7 9 11 13 15
[5]    X3←X3[X2]
[6]    →X3
[7]    T1001
[8]    →17
[9]    T1002
[10]   →17
[11]   T1004
[12]   →17
[13]   T1006
[14]   →17
[15]   'ERROR NUMBER12;TABLE 1000'
[16]   →TERMINATE
     ∇
```

```
∇T1001[⎕]∇
     ∇ T1001;S;X3;X4;X5
[1]    S←1
[2]    'ENTER VALUE POSITION; NO=1  NC=2'
[3]    VLUPOS←⎕
[4]    →10-(3=(1 2 ⍳VLUPOS))×5
[5]    'VALUE POSITION ENTERED NOT VALID; TRY AGAIN'
[6]    →7+(4=(S+1))
[7]    →2
[8]    'ERROR NUMBER   ; TABLE 1001'
[9]    →TERMINATE
[10]   →11+((VLUPOS=2)×5)
[11]   X3←(+/(~(PA⍳ 3615 5515)))+1
[12]   →13+((3=X3)×6)
[13]   X5← 60 70
[14]   ACT←X5[X3]
[15]   →21
[16]   X3←(+/(~(PA⍳ 3615 5815)))+1
[17]   →18+((3=X3)×1)
[18]   →13
[19]   'ERROR NUMBER 13; TABLE 1001'
[20]   →TERMINATE
[21]   →22
     ∇
```

```
∇T1200[□]∇
    ∇ T1200
[1]   '                          VALVE SPECIFICATIONS'
[2]   '                          ********************'
[3]   '  '
[4]   ''ITEM NUMBER:                          QUANTITY:'
[5]   'SERVICE:';SERV
[6]   '  '
[7]   '  '
[8]   'BODY SIZE       :';AO;'   INS'
[9]   'CLASS           :';CLASS
[10]  'FLUID           :';FLUID
[11]  'CAPACITY        :';W;'    LBS/HR        ';Q;'     SCHF'
[12]  'INLET PRES      :';PA;'   PSIA'
[13]  'PRES DROP       :';PD;'   PSI'
[14]  'TEMPERATURE     :';T;'    DEGREES F'
[15]  'SP GRAVITY      :';SPG;'  .'
[16]  '  '
[17]  '  '
[18]  'BODY PRESSURE STANDARD:';PRSTD
[19]  'BODY MATERIAL           :';BDYMAT
[20]  'ACTUATOR SIZE           :';ACT
[21]  '  '
[22]  '  '
[23]  'ACCESSORIES:'
[24]  '  '
[25]  '  '
[26]  '  '
[27]  'SHIPPING WGT:'
[28]  'AIR CONSUMPTION:'
[29]  'REMARKS:'
[30]  '  '
[31]  '  '
[32]  '  '
[33]  T1201

∇T1201[□]∇
    ∇ T1201
[1]   '                  VALVE PRICE MAKE UP'
[2]   '                  *******************'
[3]   '  '
[4]   '  '
[5]   'ITEM NUMBER:                          QUANTITY:'
[6]   '  '
[7]   '  '
[8]   '        DESCRIPTION                                     PRICE'
[9]   '  '
[10]  'BODY    PRESSURE STANDARD:';PRSTD
[11]  '        MATERIAL          :';BDYMAT;'                    ______'
[12]  '  '
[13]  'ACTUATOR            SIZE  :';ACT;'                       ______'
[14]  '  '
[15]  'ACCESSORIES                                              ______'
[16]  '                                                         ______'
[17]  '                                                         ______'
[18]  'SHIPPING WEIGHT                                          ______'
[19]  '  '
[20]  '  '
[21]  '                          TOTAL PRICE                    ______'
[22]  '                          x QUANTITY                     ______'
    ∇
```

APPENDIX E.

COST ANALYSIS.

E.1. COST ANALYSIS ASSUMPTIONS.

There are five basic control systems offered by Instrument suppliers. These systems are somewhat similar from supplier to supplier. Also, the design procedure, and proposal preparation procedure for each type and supplier are somewhat the same.

For this reason, a detailed cost analysis, which compared an automated procedure to current procedures, was performed for only one type of system. The system was chosen as the most representative of all suppliers and control system types available. The conclusions drawn were then proportionally applied to all types of control systems. These conclusions are based on the following underlying assumptions which are typical of the average Instrument company:

1) The cost analysis was performed for a three year period. It was assumed that an Instrument company would only automate a control system design procedure that was not expected to change for at least three years.

2) It was assumed that 50 proposals would be prepared annually, each requiring approximately 60 man/hours preparation time.

3) Labour costs have been set at $12 per man/hour for proposal engineering time, and $6 per man/hour for clerical time.

4) It was assumed that costs for office stationary, reproduction, photocopying, telephone, postage, telex and other sundries would not be affected by the automation of the design procedure.

5) A proposal has been assumed to contain 50 pages. The cost per page for stenographic labour was assumed to be $0.65.

6) The time presently spent for specification analysis activities has been set at 25% of the time be required to produce a design and proposal. This would not be affected by automation of the design procedure.

E.2 DETAILED COST ANALYSIS.

E.2.1. Manual Method.

1) Cost: Year One.

a. For proposal engineering costs, consider 50 proposals per annum, at 60 hours per proposal, at $12. per hour.
Proposal Cost = 50X60X12X0.75 = $27,000.-

b. For stenographic costs, consider 50 proposals per annum, at 50 pages per proposal at $0.65 per page.
Stenographic Cost = 50X50X0.65 = $1,620.-

Total Cost - Year One	= $28,620.-	
Total Cost after Year One		$28,620.-

2) Cost: Year Two.

a. Repeat Year One =	$28,620.-	
Escalation at 6% =	1,715.-	
Total Cost - Year Two =	$30,335.-	
Total Cost after Year Two		$58,955.-

3) Cost: Year Three.

a. Repeat Year Two =	$30,335.-	
Escalation at 6% =	1,820.-	
Total Cost - Year Three	$32,155.-	
Total Cost after Year Three		$91,110.-

E.2.2. Automated Method.

The cost of an automated method consists of the normal operation costs plus the development costs. It is assumed that the development costs would be paid over three years.

Development Costs:

1) Estimated design and development costs including materials and equipment, based on implementation within four months from date of commissioning.

Human Development Costs = $12,800.-

2) Estimated cost for computing, connect and terminal facilities required for development.

Machine Development Costs = $23,040.-

Total Development Cost: = $35,840.-

3) Cost each year, for Three Years $12,000.-

Operation Costs:

1) Cost: Year One.

a. For proposal engineering costs, consider 50 proposals per annum, at four hours per proposal (this is based on the conclusion from CAPP that an automated system requires only 10 percent of the time taken by a manual method), at $12. per hour.

Proposal Cost = 50 X 4 X 12 = $2,400.-

b. For stenographic costs, consider 50 proposals per annum, at ten pages per proposal at $0.645 per page.

Stenographic Cost = 50 X 10 X 0.645 = $323.-

c. Estimated cost for computing, connect and terminal facilities, required for first year operation. Assumes 50 quotes per annum at one and a half hours per proposal.

Machine Operation Costs = $7,800.-

Total Cost Year One $10,523.-

Total Cost after Year One $10,523.-

2) Cost: Year Two.

a. Repeat (a) above	=	$2,400.-
Repeat (b) above	=	323.-
Repeat (c) above	=	7,800.-
sub-total	=	$10,523.-
Escalation at 6%	=	632.-

$11,155.-

b. Estimated cost for maintenance including computing, connect, and terminal facilities as well as development labour.

Maintenance Costs = $4,480.-

Total Cost Year Two $15,635.-

Total Cost after Year Two $26,158.-

3) Cost: Year Three.

a. Repeat Year Two = $15,635.-

b. Escalation at 6% = 938.-

Total Cost Year Three 16573.-

Total Cost after Year Three $42,731.-

E.2.3. Comparison.

Table E.1. Cost Comparison.

	Total First Three Years	Each Additional Year
Current Manual Procedure	$91,110.00	$32,155.00 Plus esc.
Proposed Automated Method including Development & Operation Costs	$78,571.00	$16,573.00 plus esc.
Cost Difference	$12,539.00	$15,582.00
Approximate % Saving	15%	50%
Approximate total Saving for Five Systems	$60,000.00	$80,000.00